University of Alberta

Drinking Water Quality in Buildings
A Monitoring Study

By

Kirsten Melanie Pinney ©

A thesis submitted to the Faculty of Graduate Studies and Research
In partial fulfillment of the requirements for the degree of

Master of Science

in

Environmental Science

Department of Civil and Environmental Engineering

Edmonton, Alberta

Fall 2006

Library and
Archives Canada

Published Heritage
Branch

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque et
Archives Canada

Direction du
Patrimoine de l'édition

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence
ISBN: 978-0-494-22345-1
Our file Notre référence
ISBN: 978-0-494-22345-1

NOTICE:
The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:
L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.

Canada

ABSTRACT

The goal of this study was to determine best management practices and procedures to ensure optimal water quality in large, intermittent-use facilities. The study included a survey and assessment of drinking water quality within intermittent use public buildings.

Results indicated that the water quality (primarily aesthetic) tended to deteriorate within the building distribution systems relative to the water quality in the municipal distribution system. Overall water quality deterioration occurred after extended periods of low water use, at points throughout the building with minimal water use and water flow and age of the building. Site specific, follow-up surveys were carried out to investigate potential problem areas and to develop recommendations for management strategies, such as routine building plumbing flushing procedures. Information gained in this preliminary survey is applicable to large facilities with similar water use patterns, and will serve to enhance public health standards for water quality.

ACKNOWLEDGEMENTS

I would like to very gratefully acknowledge the financial support I received for this project which was provide by The University of Alberta and EPCOR Utility Services. I would also like to extend my gratitude to the members of my steering committee for their guidance; from The University of Alberta: Dr. Stephen Craik (supervisor), Dr. Mohamed Gamal El-Din (co-supervisor), who were also my thesis advisors and Dr. Warren Kindzierski, from EPCOR Utility Services: Carol Bruineman, Dr. Les Gammie, and Greg Hogge, from Capital Health: Karen Emde and Nelson Fok and from Edmonton Public Schools: Mike Brown, Elli Culligan, Darryl Markus and Jean Westergard. Further thanks are extended for the services of Margaret French, John Paran and Ian van Beers at the EPCOR Water Services Water Quality Assurance Laboratory. Many thanks is given to all the Principals and facility personal at the schools for their time and patients, through which this project was made possible.

Much thanks and great appreciation is given to my family for all their support. My parents, who made it possible for me to achieve a great education and all the encouragement my brother gave me. Last, but certainly not least I would like to thank my friends who were always there for me.

Everyone's support, patience and enthusiasm never let me falter.

TABLE OF CONTENTS

ABSTRACT
ACKNOWLEDGEMENTS
TABLE OF CONTENTS
LIST OF TABLES
LIST OF FIGURE
LIST OF ABBREVIATION

1.0 INTRODUCTION 1
- **1.1 Background Information** 1
- **1.2 Study Objectives** 2

2.0 LITERATURE REVIEW 4
- **2.1 Water Quality** 4
- **2.2 Drinking Water Quality Guidelines** 4
- **2.3 Drinking Water Quality Protection** 7
- **2.4 Multi-barrier Protection** 8
- **2.5 Municipal Distribution System** 10
  - *2.5.1 Water Age in the Distribution System* 10
  - *2.5.2 Backflow, Backsiphonage and Backpressure* 12
  - *2.5.3 Problems Associated with Cross-Connections and Backflow* 14
  - *2.5.4 Optimizing the Distribution System* 15
- **2.6 Building and Domestic Plumbing Distribution Systems** 16
  - *2.6.1 Chemical Water Quality in Building Distribution Systems* 17
  - *2.6.2 Microbial Water Quality in Building Distribution Systems* 18
  - *2.6.3 Best Practices for Optimal Water Quality in Internal Distribution Systems* 24
- **2.7 Literature Review Summary** 25

3.0 EXPERIMENTAL METHODS 26
- **3.1 Survey Design** 26
- **3.2 Sampling Protocol** 30
- **3.3 Water Quality Analysis** 31
- **3.4 Analytical Procedures and Quality Assurance and Quality Control** 33
- **3.5 Data Evaluation** 36

4.0 RESULTS AND DISCUSSION 38
- **4.1 General Assessment of Building Water Quality** 38
  - *4.1.1 Total Combined Chlorine Residual* 41
  - *4.1.2 Turbidity* 44
  - *4.1.3 Lead* 46
  - *4.1.4 Copper* 47
  - *4.1.5 Microbiological Data* 49
- **4.2 Impact of Experimental Factors on Measured Water Quality** 51
  - *4.2.1 Time of Sampling the Week* 53
  - *4.2.2 Sampling Location within the Buildings* 54
  - *4.2.3 Building Water Utilization Rate* 56
  - *4.2.4 Building Age* 58
- **4.3 Additional Discussion of Individual Measured Parameters** 61
  - *4.3.1 Total Combined Chlorine Residual Discussion* 61
  - *4.3.2 Turbidity Discussion* 64
  - *4.3.3 Lead and Copper Discussion* 64
  - *4.3.4 Microbiological Parameter Discussion* 70

5.0 CONCLUSION 75

6.0 RECOMMENDATIONS 79

7.0 REFERNCES 82

8.0 APPENDICES 86
Appendix A. Map of EPS Ward Breakdown 86
Appendix B. Initial Information Sheet 87
Appendix C. Letter to Principal 88
Appendix D. Information Sheet 90
Appendix E. Information for Staff and Students 93
Appendix F. Sampling Details 94
Appendix G. Exposure Assessment 98
Appendix H. Pipe Material 100
Appendix I. Monday Building Samples 101
Appendix J. Wednesday Building Samples 105
Appendix K. Monday Municipal Samples 109
Appendix L. Wednesday Municipal Samples 111
Appendix M. Building 4 Timed Samples 113
Appendix N. Building 6 Timed Samples 114
Appendix O. Building 20 Timed Samples 117
Appendix P. Odour Samples 119
Appendix Q. Building 6 Flush Samples 121
Appendix R. Replaced Fountain Samples 122
Appendix S. Building 19 Timed Samples 123

LIST OF TABLES

Table 1. Breakdown of school types within Edmonton public school system. 26

Table 2. Benchmark guidelines used in the study derived from Health Canada (2006) guidelines and industry practices. 33

Table 3. Standard method used in sample analysis. 34

Table 4. Summary of water quality entering the distribution system and residential water main samples. 40

Table 5. Effect of fountain flushing on HPC bacteria concentrations. 71

LIST OF FIGURES

Figure 1.	Distribution of water utilization rates of schools in the Edmonton public school system in 2004/2005 percentage.	27
Figure 2a.	Total combined chlorine concentration for first-run Monday morning samples collected from all locations. The horizontal line is the benchmark value of 0.1 mg/L total chlorine.	43
Figure 2b.	Total combined chlorine concentration for mid-week, normal use Wednesday samples collected from all sample locations. The horizontal line is the benchmark value of 0.1 mg/L total chlorine.	43
Figure 3a.	Turbidity concentration for first-run Monday morning samples collected from all locations. The benchmark value of 5NTU is greater than the Y-axis.	45
Figure 3b.	Turbidity concentration for mid-week, normal use Wednesday samples collected from all sample locations. The benchmark value of 5NTU is set at the maximum on the Y-axis.	45
Figure 4a.	Lead concentration in first-run Monday morning samples collected from all sample locations. The horizontal line is the benchmark value of 20 ppb lead.	46

Figure 4b. Lead for mid-week, normal use Wednesday samples collected from all sample locations. The benchmark value of 20 ppb is set at the maximum on the Y-axis. 47

Figure 5a. Copper concentration in first-run Monday morning samples collected from all sample locations. The horizontal line is the benchmark value of 1.0 mg/L copper. 48

Figure 5b. Copper for mid-week, normal use Wednesday samples collected from all sample locations. The horizontal line is the benchmark value of 1.0 mg/L copper. 48

Figure 6a. HPC concentration in first-run Monday morning samples collected from all sample locations. The horizontal line is the benchmark value of Log 2.7 CFU/mL (500 CFU/mL) HPC concentration. 50

Figure 6b. HPC concentration for mid-week, normal use Wednesday samples collected from all sample locations. The horizontal line is the benchmark value of Log 2.7 CFU/mL (500 CFU/mL) HPC concentration. 50

Figure 7. Box blots of parameter concentrations for Monday and Wednesday samples collected from all locations. 54

Figure 8. Box plots of parameter concentrations as function of within-building sample location. 56

Figure 9. **Box plots of parameter concentrations for water utilization rates (m^3/month).** **58**

Figure 10. **Box plots of parameter concentrations as function of building age.** **60**

Figure 11a. **School 6 total combined chlorine concentration (mg/L) over a one hour time period.** **62**

Figure 11b. **School 20 total combined chlorine concentration (mg/L) over a one hour time period.** **62**

Figure 12a. **School 4 Monday morning lead concentration (ppb) over a one hour time period.** **65**

Figure 12b. **School 4 Wednesday morning lead concentration (ppb) over a one hour time period.** **66**

LIST OF ABREVIATIONS AND SYMBOLS

°	Degrees
^{0}C	Degrees Celsius
<	Less than
>	Greater than
*	Outliers
○	Extreme outliers
%	Percent
p	p-value
AB	Alberta
AE	Alberta Environment
AO	Aesthetic Objective
ANOVA	Analysis of variance
APHA	American Public Health Association
AWWA	American Water Works Association
CO_2	Carbon dioxide
CCME	Canadian Council of Ministers of the Environment
CAEAL	Canadian Association for Environmental Analytical Laboratories
CFU	Colony Forming Units
DPB	Disinfection by-products
DPD	diethyl-p-phenylene diamine
E. coli	*Escherichia coli*
EPCOR	EPCOR Water Services Incorporated
EPEA	Environmental Protection and Enhancement Act
EPS	Edmonton Public Schools
H_2S	Hydrogen sulfide
HC	Health Canada
HPC	Heterotrophic Plate Count
ISO	International Organization for Standardization
kPa	kilopascal

KI	Potassium iodide
KW	Kruskal-Wallis
L	Litre
MAC	Maximum Acceptable Concentration
m^3	Cubic meters
mL	Millilitre
mg/L	Milligrams per litre
NA	Not applicable
NCl_3	trichloramine
NH_2Cl	monochloramine
$NHCl_2$	dichloramine
NTU	Nephelometric Turbidity Units
P/A	Presence/Absence
ppb	Parts per Billion
psi	pound per square inch
QC/QA	Quality Control and Quality Assurance
RHA	Regional Health Authority
SW	Shapiro-Wilks
TC	Total Coliforms
TOC	Total Organic Carbon
TSS	Total Suspended Solids
µg/L	Microgram per litre
USEPA	United States Environmental Protection Agency
WEF	Water Environment Federation
WHO	World Health Organisation

1.0 INTRODUCTION

1.1 Background Information

A well-operated water treatment facility can consistently produce finished water of quality that exceeds health and aesthetic standards or guidelines. The finished quality may deteriorate within municipal distribution system piping that conveys water to individual households and buildings. Most large municipalities monitor water quality within the distribution system and attempt to mitigate water quality deterioration through regular flushing or replacement / upgrading of mains. Deterioration of water quality within the distribution system may also occur at points closer to the tap, that is, within internal building piping.

The purpose of a distribution system is to distribute drinking water to populations easily and safely. The distribution system is the final protection barrier in the multi-barrier approach to water treatment. Assessment of water quality in a distribution system is a very complex task that requires consideration of several physical, chemical and biological water quality parameters and the interaction between those parameters (Besner et al. 2001). The interaction of water quality parameters is not limited to the municipal distribution system; many physical, chemical and biological interactions occur after the water leaves the municipal distribution system and enters the internal building distribution piping. In fact, there is greater potential for interaction between the water and the pipe material in building distribution systems because the surface area to volume ratio increases as the pipe size decreases (Brazos et al. 1986). Several studies have been conducted with respect to water quality within the municipal distribution system, but only a limited number of studies have addressed the issue of building distribution systems. There is a need to gather preliminary information on basic water quality parameters within building distribution systems.

There is especially little information on water quality in large buildings used by the general public such as schools, hospitals, offices buildings, apartment complexes and other institutions. The plumbing systems in these kinds of facilities are generally more extensive and complex than those of single family dwellings and, therefore, the water may reside for longer periods within the building piping. This is exacerbated by the fact that many of these large facilities are of low and intermittent water use and are left vacant over nights, weekends and during holidays. Another issue to consider is that the public has little direct control over the quality of the water they consume in these facilities, as they might have in their homes and they may place a blind trust in the integrity of the water supplied. An informed homeowner can easily run their tap for a few minutes to flush stagnant water from the plumbing of their house before taking a drink. This approach may not be as effective in large buildings.

1.2 Study Objective

The primary objective of this study was to assess water quality in large, intermittent water use facilities and to determine if best practices should be recommended to ensure optimal water quality in these kinds of facilities. The first hypothesis to be tested was that the water quality deteriorated in internal school distribution systems once it left the water main. Deterioration was based on measured water quality parameters (combined chlorine residual, turbidity, lead, copper, HPC bacteria). The second hypothesis to be tested was that water deterioration was a function of selected school variables such as, sampling time during the week, sampling location within the building, building water utilization rates and building age. Water quality deterioration would be greatest after periods of stagnation or low water use.

The study was a joint cooperative effort between EPCOR Water Services, The University of Alberta, Capital Health and Edmonton Public Schools (EPS). A steering committee was established before the study began to provide overall direction for the study and to ensure that all tasks and goals for all parties involved were being met. The steering committee consisted of several advisors from each of the aforementioned groups.

The investigation examined the effect of several variables, such as location within the building at which water samples were taken, time of week when samples were taken, building age and water utilization rate, on measured water quality parameters. Often large buildings, such as office buildings or schools, are left almost vacant over weekends or during holidays, resulting in low or intermittent water use in the building. There is a need to determine if specific procedures, such as routine flushing of building plumbing, are necessary or are warranted in order to maintain consistently high levels of water quality in these types of buildings. Consideration of such procedures must take into account additional factors such as practicality, cost, possibility of increased water consumption and adverse public reaction.

For this study, public school buildings were selected as the study group to represent large intermittent water use public buildings for the following reasons. Firstly, a cooperative arrangement with the local school board facilitated access to the facilities for water quality sampling. Secondly, there were approximately 200 schools within the local public school system. This provided a relatively large population of buildings from which to draw a random sub-sample of buildings representing different building sizes and ages. In addition, school facilities were ideal for this kind of study because the water use patterns tend to be fixed and predictable, that is heavy use during the week and little or no use on the weekends.

2.0 LITERATURE REVIEW

2.1 Water Quality

Water quality, whether the water is being used for drinking, recreational or irrigational purposes, is significant to the health of all humans in both developed and non-developed countries (Fewtrell and Bartram 2001). The World Health Organisation (WHO) states that drinking water should be suitable for human consumption and for all normal domestic purposes. The WHO defines drinking water as any water or ice which is intended for human consumption. The definition continues and states that drinking water should be safe for lifetime use, taking into account differing sensitivities that occur across different societies and life stages (WHO 2004). Those at the greatest risk from poor water quality include young children, elderly and immune deficient individuals. Due to the fact that water is essential for life, one of the main health goals of any country, government or industry should be to provide water quality to all of society that meets all health-related standards. Improving the quality of water will in turn improve the quality of life, as access to safe drinking water can result in tangible health benefits for all people (WHO 2004).

2.2 Drinking Water Quality Guidelines

In order to protect public health, a considerable amount of effort has been invested to define conditions and to establish regulations that would allow for the safe use of potable water. Specific water quality guidelines have been implemented by many countries and nations with some variation occurring among the regulations. The WHO has provided some guidelines that are intended to implement risk management strategies that will ensure the safety of all drinking water supplies by way of controlling hazardous constituents which can be present in drinking water (WHO 2004). The WHO guidelines are intended to be used for a range of systems, from large metropolitan piped systems to small community systems. The guidelines are also applicable to individual dwellings and large buildings (WHO 2004).

The WHO guidelines do not attempt to promote the adoption of international standards but rather they provide a scientific departure point from which national governments and authorities may develop regulations and standards which are appropriate to individual national situations (WHO 2004). Specific water quality guidelines have been implemented by many countries and nations with some variation occurring among the regulations. At a minimum the guidelines are benchmarks set for safe practice in regards to public health protection.

In Canada the drinking water quality guidelines are developed and maintained by the Canadian Council of Ministers of the Environment (CCME) and Health Canada (HC). Criteria summaries for each drinking water contaminant listed in the guidelines are prepared by the staff of the Water Quality and Health Bureau of the Safe Environments Programme of Health Canada. These documents provide a critical evaluation of available information on exposure, health effects, analytical methodology and treatment technology for each contaminant (HC 2006). The guidelines were developed by monitoring substances in water and by conducting research on constituents found in water which can adversely affect water quality. The guidelines contain maximum acceptable concentrations (MAC) and aesthetic objectives (AO) for microbiological, chemical, physical and radiological parameters of potable water (HC 2006). Currently, the guidelines regulate approximately 85 different parameters (HC 2006).

Depending on the provincial or territorial government, adherences to the guidelines are either voluntary or mandatory. In most provinces, including Alberta, the guidelines, in whole or in part, have now been adopted as mandatory minimum drinking water quality requirement. In the province of Alberta potable water is regulated by Alberta Environment (AE) under the Environmental Protection and Enhancement Act (EPEA) and the Potable Water Regulation 277/2003 (HC 2006). Alberta Environment has adopted all health related guidelines set by CCME as regulation; aesthetic guidelines set by CCME are not legally enforced in Alberta. However, important consideration is given to each individual water treatment plant approval; any guideline set out in the approval is considered a regulation. Therefore, the Potable Water Regulation enforces all health related CCME guidelines as legal requirements for all drinking water in Alberta (AE 2002). There is an exception regarding fluoride. The CCME guideline for fluoride is 1.5mg/L, however, in Alberta, naturally occurring fluoride in ground water can reach levels as high as 2.4 mg/L (Canadian Legal Information Institute (CanLII) 2006a).

It is important to note that potable water within the internal building systems is not formally regulated to the same standards as the municipal distribution system. The potable water regulations stop at the water service connection into any privately owned developments, which includes recreational facilities, schools, hotels, motels, restaurants, community centers, work camps, campsites, information centers or any other similar facility which is on a parcel of land which does not include single family dwellings and farms (CanLII 2006a). Water supplied within buildings is covered under the provincial Public Health Act, Nuisance and General Sanitation Regulation 243/2003 (CanLII 2006b). The regulation allows Health Inspectors to enter privately owned facilities to collect water samples and to ensure that the water supplied can be considered potable. Therefore, there is no formal requirement to ensure that the water meets specific water quality criteria. For example, there is no requirement that the total combined chlorine residual in the water samples collected from privately owned facilities exceeds a guideline level or that the turbidity is below a certain guideline level. However, it is the responsibility of the Alberta Health Department to decide if the drinking water presented a health risk. Alberta Health must be informed if total coliforms or *Escherichia coli* are found in any water sample, and follow-up remedial actions are required until samples are negative.

The federal guidelines and provincial regulations are an essential part of the multi-barrier approach to maintaining a high level of drinking water protection from the source to the tap.

2.3 Drinking Water Quality Protection

In order to ensure the highest level of water quality one must look at the entire system of water supply, water treatment and water distribution as a whole. Managing the overall system of source water to tap water ensures the functioning of a unit rather than individual parts. The most effective management plan with regards to drinking water systems is the implementation of a multi-barrier approach. The multi-barrier approach integrates three major systems all of which play an active role in the protection of drinking water and public health. The major systems are: source water protection, the water treatment plant and the water distribution system (HC 2002). Each system should be safeguarded with the following procedures: management, monitoring, research and development, specific guidelines with legislative policy and public awareness (HC 2002). Although, no system is one hundred percent protected the multi-barrier approach is the best known practice which helps to prevent and reduce the contamination of drinking water from the source to the tap (HC 2002).

2.4 Multi-barrier Protection

Source water protection is the key element in maintaining water quality over time (HC 2002). Source water can be defined as any water body from which water is drawn for the purpose of human consumption. Source water is categorized into two major groups; surface water and groundwater. The quality of ground water is usually much higher than that of surface water. Most of Alberta gets its drinking water from surface water sources. The hydrologic cycle indicates the constant movement between surface and groundwater in the environment (AWWA 1999). Typically, source water contamination will occur through the hydrologic cycle as contaminants can be diluted, transported and concentrated through the cycle (AWWA 1999). Therefore, the goal of source protection must be to reduce or eliminate the input of contaminants within a watershed. A watershed is defined as a geographic location in which all water draining from that area drains into a specific stream, creek or river which is the source intake. Watersheds are defined by natural hydrology and represent the best way to manage water resources (USEPA 2004). Due to the vastness of many watersheds the management and protection requires the cooperation of all stakeholders involved to develop and maintain plans which increase water quality and reduce pollution sources within the watershed (HC 2002). Water quality is a direct result of human and environmental activities and interactions within the watershed. Watershed management offers a strong foundation for uncovering problems that may be affecting a watershed (USEPA 2004). The effective management of a watershed and, in turn, source water will minimize public health risk and reduce the degree of drinking water treatment required (HC 2002).

The degree to which water must be treated is dependent on the quality of the incoming source water as well as the desired output quality of the finished water (Reynolds and Richards 1996). Therefore, by monitoring the source water the level of treatment may be adjusted with changes in the source water composition and quality. The major source water characteristics which are used to determine treatment requirements and treatment plant design are turbidity, pH, temperature, alkalinity, total organic carbon (TOC), total suspended solids (TSS), microbiological quality, algae counts, and iron and manganese concentration (HC 2002). The design of a water treatment plant is a complex task and is usually site specific.

A water treatment plant will consist of several unit operations and processes which can be classified as physical, chemical or biological (Reynolds and Richards 1996). In a water treatment plant basic physical unit operations are sedimentation, flotation and granular bed filtration, while basic chemical unit processes are coagulation, flocculation and chlorination (Reynolds and Richards 1996). Conventional treatment is typically the choice treatment in producing high quality drinking water (HC 2002). Conventional treatment typically involves coagulation, flocculation, sedimentation, filtration and disinfection. The most common types of surface water treatment are rapid sand filtration, clarification/sedimentation and lime/soda softening plants. In the case of ground water, the quality of water is usually much higher and often the only treatment which is needed is gas stripping, to remove supersaturated gases such as H_2S or CO_2 if they are present, and chlorination to provide a residual disinfectant in the distribution system (Reynolds and Richards 1996).

Selection of a water treatment design is based on the need to meet regulatory water quality goals in the finished water while providing service at an acceptable cost to the consumer (AWWA 1999). However, design selection must also take into account the quality of water which needs to be maintained in the distribution system (AWWA 1999), as water quality deterioration in the distribution system could lead to regulatory non-compliance of water provided to the customer. The treatment process selected should ensure or enhance water stability (AWWA 1999), which will help maintain water quality throughout the distribution system. The finished water leaving the treatment plant must meet stringent regulations; these regulated parameters must be maintained throughout the distribution system. In order to maintain water quality both chemically and biologically throughout the distribution system the network needs to be designed to prevent contaminants from entering, to maintain a disinfectant residual and to minimize transit time (Ainsworth 2004).

2.5 Municipal Distribution System

In order for the distribution system to maintain the goal of a protective barrier it must be designed, maintained and operated with the highest quality management in mind. This will be essential when meeting current and future regulatory requirements (Kirmeyer et al. 2005). Water quality deterioration in the distribution system can take place even though the water treatment processes are designed and to produce high quality water. The reactions that result in water deterioration often occur at the interface between the bulk water and the pipe surface and are a function of the bulk water chemistry and the pipe surface material (Kirmeyer et al. 2005). There are three main operational controls which can be used to reduce the deterioration of water in the distribution system: reduce the water detention times, maintain positive pressure and control the direction and the velocity of the flowing water (Kirmeyer et al. 2005).

2.5.1 Water Age in the Distribution System

Water leaving the water treatment plant is highly regulated which produces optimal water quality. However, reactions can occur in the distribution system between water and pipe surfaces, they can be chemical or biological with time, most reactions are rate-determined processes. That is, the extent of reaction will be determined by duration contact between an element of fluid

and the pipe surface. The contact time can be reduced by either reducing the length and volume of the piping, or by increasing the water flow rate. Reducing the detention time within the building piping will mean that undesirable contaminants that may be formed at the pipe surfaces are flushed from the system and do not have time to accumulate.
Anaerobic or anoxic conditions can occur when oxidation reactions at the pipe surface (i.e. rusting or biological oxidation of organic matter within biofilms) results in depletion of oxygen in the bulk liquid. A reduction in dissolved oxygen will result in deterioration of water quality and poor taste and odour. Therefore, decreasing residence time will aid to avoid anaerobic or anoxic conditions, which will help reduce water deterioration.

Water velocity and residence time are related. The distribution system should not have excessive capacity which will result in long transit times, unless the excess capacity is required to meet known or anticipated water demands in the future (Ainsworth 2004). However, most municipal distribution systems are designed based on fire-fighting flows. As a result, they are over-designed for normal use. The pipe diameters are too large and the resulting velocities too low. To some extent by ensuring that velocity remains high throughout the distribution system the accumulation of debris and biofilms on the surface of the piping can be controlled.

Many North American distribution systems are not designed to create a high velocity throughout the system. This is because North American distribution systems are designed to accommodate the quick distribution of large amounts of water (i.e. fire fighters) needed in the event of an emergency. In contrast, many European countries design distribution systems to ensure overpressure within the system with reduced residence times (van Howelingen 2006).

Detention time in distribution systems is highly variable and is a function of water demand, velocity, system operation and system design (USEPA 2002b).

All of these factors will vary greatly between communities, and with time of day, seasons and land use patterns (USEPA 2002b). Water quality problems that can be attributed to long detention times and low velocities include increases in the formation of disinfection by-products (DBP), microbial growth, taste and odour, metallic content (iron and copper), sediment deposition and increases in temperature (Kirmeyer et al. 2005; USEPA 2002b). The minimization of water age and the increase of velocity can be implemented and maintained by means of tracer programs, modeling and hydraulic design (USEPA 2002b).

2.5.2 Backflow, Backsiphonage and Backpressure

A cross-connection occurs when a non-potable water line (such as a wastewater line) is connected directly to or comes into contact with a potable water line. Cross-connections are generally unintentional and occur through improper plumbing practices or inappropriate (illegal) connections to the distribution system. Backflow is when non-potable water flows into the distribution system via a cross-connection and mixes with potable water. Backflow problems are directly related to pressure within the distribution system, infiltration and cross connections (USEPA 2002a). The pressure at every point in the distribution system should be maintained below the maximum pressure that will cause the pipe to burst (the maximum design pressure) but above a minimum pressure that will provide adequate flow velocities and protection against backflow (Ainsworth 2004). Backflow can occur in three manners: negative pressure in the distribution line, infiltration and a pressure in the cross connection line that is greater than the positive pressure in the distribution line (USEPA 2002a).

A negative pressure drop in the distribution line may be caused by changes in the water column, locally high water demand, line breaks or any other event that causes the water to flow in a reverse direction. When there is a negative pressure in the distribution system it creates the potential for non potable water to be siphoned back into the water distribution line via a cross connection (USEPA 2002a). Maintenance of a positive pressure in the distribution system reduces the potential for backsiphonage to occur even when cross-connections exist (Kirmeyer et al. 2005). Another way in which backsiphonage can result in contamination is through infiltration. All distribution systems and sewer systems leak or are pervious to some extent. If a potable water distribution system pipe is in the vicinity of a leaking sewer pipe (i.e. they were placed in the same trench), then a negative pressure within the potable water distribution system could result in backsiphonage of the wastewater. Good management and operating practices have concluded that a minimum pressure throughout the distribution system should be maintained at a suggested 20 psi or 138 kPa (Kirmeyer et al. 2005).

Backpressure can occur when a non-potable line which is operating at a higher pressure is connected to a potable water line. The higher pressure can be created by means of a pump, a high pressure boiler, higher elevation or steam or air pressure (USEPA 2002a). If a cross-connection exists, the flow of water will be from the non-potable line to the potable line whenever the pressure at the point of a cross connection exceeds the pressure of the distribution system (USEPA 2002a). The risk of backpressure can be reduced by means of implementing a cross connection control program which will include regular inspection and monitoring programs in attempts to eliminate cross connections (Kirmeyer et al. 2005). Backflow prevention devices may also be used as to minimize the potential for backpressure due to undetected cross-connections. The most common backflow prevention devices include air gaps, break tanks and mechanical backflow prevention valves (Ainsworth 2004). Air gaps and break tanks are the most basic forms of protection. Mechanical backflow prevention valves are subject to wear and tear and are prone to failure (Ainsworth 2004). Mechanical backflow devices are very commonly installed for temporary premise isolation or to isolate hazardous sections of buildings. The city of Edmonton requires all commercial and industrial sites with any moderate hazard to have mechanical backflow devices (personal communication with Les Gammie of EPCOR).

2.5.3 Problems Associated with Cross-Connections and Backflow

Significant problems can arise from cross connections and backflow incidents, which may have serious risks associated with them. The associated risk is often characterized by the type and amount of contaminant entering the system and its associated health effects (USEPA 2002a). Cross-connection associated issues may have both direct health impacts (i.e. drinking sewage will make you sick) or indirect impacts on water quality (i.e. it might provide food for biofilm growth which may result in poor taste and odour). The direct effects are the most immediate concern. It is very difficult to predict the contaminant fate in the distribution system as it is often system specific and depends on several variables (USEPA 2002a).

The most important variables in determining the fate of the contaminant are the hydraulics of the system and the physical, chemical and biological properties of the contaminant (USEPA 2002a). The contaminant may remain as a slug in a localized area; it may be dispersed upstream and down stream of the point of contamination or it may be adsorbed to the interior lining of the pipe (USEPA 2002a). The contaminant may also form or become concentrated in a biofilm and may be released slowly through erosion or sloughing causing long term effects on the overall water quality in the distribution system and risk to public health (USEPA 2002a). The release of a contaminant into the distribution system will also produce several side issues such as increased microbial and biofilm growth, reduction of residual disinfectant, turbidity, corrosion, metallic contamination and taste and odour.

2.5.4 Optimizing the Distribution System

The need for best management practices and the optimization of distribution system is becoming an ever present issue throughout North America as many distribution systems are deteriorating with age. In the past much consideration has been given to minimizing the cost of construction and maintenance of distribution systems within buildings (Lansey and Mays 1990). The current emphasis however, is to ensure a better balance between distribution system hydraulic design and water quality (Kirmeyer et al. 2005). In order to ensure a balance between system design and water quality, areas of importance in the distribution system must be prioritized. Priorities throughout North America regarding optimization of aging distribution systems vary widely. Many utility companies believe that investing in renewal of an old distribution system is proper maintenance, while others adopt a strategy according to which they will not invest in repairs until a failure has occurred (Grigg 2005).

Kirmeyer et al. (2005) have recommended a stepwise approach to aid in the design of an optimization plan regarding the distribution systems. The steps of this approach are:

1. Understand the distribution system design and factors which have a role in maintaining water quality in the system and define potential problems in the distribution system;
2. establish and set water quality goals which need to be achieved;
3. research and select the most appropriate approach to achieve the set goals;
4. implement the plan and design set out in the above steps, ensure the plan is effective through monitoring and;
5. develop standard performance goals and operating procedures which must be met (Kirmeyer et al. 2005).

The stepwise approach will provide utility companies with the information needed to make decisions about renewal, maintenance, operations, monitoring, replacements and management of a municipal distribution system. The stepwise approach is a practical method which will help to ensure and maintain water quality throughout the distribution system.

2.6 Building and Domestic Plumbing Distribution Systems

In many developed nations a system of pressurized pipes provide a means for potable drinking water to be distributed to individual buildings and domestic residences (Ainsworth 2004). The water exits the distribution system via individual service lines which are connected to each building or domestic residence. The service line passes through the water meter and is connected to the internal distribution system of the building or domestic residence where potable water can be accessed through water outlets such as faucets or drinking water fountains.

Because of the complex nature of many plumbing designs in these types of facilities water can remain stagnant for long periods of time in the building distribution system which often leads to chemical and microbial water quality deterioration. Deterioration is compounded by the fact that many of these facilities have low and intermittent water use as they are left vacant over nights, weekends and holidays. There is little information on water quality in large buildings such as schools, offices buildings, hospitals, apartment complexes and other such institutions. Few systematic studies have been published in which the influence of the building distribution systems on the quality of potable water produced has been examined.

2.6.1 Chemical Water Quality in Building Distribution Systems

Trace metals such as lead, copper, iron and zinc can leach into drinking water through pipe material. The amount of trace metals which could be present in drinking water depends on the initial water quality, how long the water remains in contact with the pipe, joint and solder material and the temperature of the water (USEPA 2005).

Singh and Mavinic (1991) conducted a study which examined trace metals (lead and copper) in seventy-two high rise apartment buildings and sixty single family houses. The following variables were examined: building height, type of building, building location, plumbing age and type of plumbing. Results indicated that all variables, with the exception of building height, were correlated with the concentration of either lead or copper. For example, lead and copper levels were significantly higher in newer buildings compared to older buildings. Viraraghavan et al. (2000) also found that the higher concentration of metals measured in drinking water decreased with the age of the building. These results are not unexpected since new joint solder material and copper piping will tend to leach lead and copper more readily than piping material that has been in service for some time. Older buildings do not tend to have high metals concentrations unless the water is corrosive, however, with non-corosive water scaling will have most likely occurred which will reduce opportunities for metals to enter into the drinking water (USEPA 2005).

In the Singh and Mavinic (1991) study, lead concentrations were significantly higher in high rise apartment buildings than in single family house. This can be attributed to two possible factors: (1) in high rise buildings water is more likely to be stagnant increasing contact time. The rate of leaching of metals (i.e. mass of metal/area/time) is likely to be constant and independent of flow rate and contact time. However, the same rate of metal leaching will result in a higher concentration in the water when the flow rate is low (and detention time is high) relative to when the flow rate is high and the detention time is low. And (2) the high rise plumbing design is more complex with longer pipe runs and more solder and joint connections from which lead may leach.

Singh and Mavinic (1991) also investigated the use of faucet flushing to reduce levels of metal concentrations in drinking water samples. The lead concentration was highest in the first 250 mL volume of water produced at the tap after first opening and decline thereafter. Copper concentration on the other hand, increased initially and peaked after 250 mL to more than 750 mL volumes water were flushed from the faucet. This is most likely a due to the fact that the lead-containing soldered joints tend to be concentrated within the last few feet of piping before the head of the water outlet. Copper piping, on the other hand is used throughout the distribution system. Flushing the last few feet of piping before the faucet head, therefore, may be effective at reducing the concentration of lead in the tap water; however, a longer flush may be required of the entire building distribution system to reduce the copper concentration.

2.6.2 Microbial Water Quality in Building Distribution Systems

Microbiological growth in a distribution system can lead to several water quality and operational problems (Bartram et al. 2003). Viable organisms which remain in the distribution system will multiply under appropriate environmental conditions (temperature and nutrition) and may produce the formations of biofilms on the internal pipe surface (Ainsworth 2004). A biofilm can typically contain a plethora of free living heterotrophic bacteria, protozoan, nematodes and fungi (Ainsworth 2004). Biofilm growth within a building distribution system can give rise to associated problems of disinfectant residual loss, higher levels of bacteria, taste, odour and appearance changes, and corrosion which is induced through microbial activity (Characklis and Marshall 1990).

A study was conducted by Augoustinos et al. (1995) with respect to bacterial re-growth and biofilm formation in the distribution system of apartment buildings (22), private houses (23) and other institutions (35). Microbial water quality in the different types and ages of buildings was compared. There was a significant decrease in water quality in apartment buildings when compared to private houses; heterotrophic plate counts (HPC) bacteria concentrations were at least two orders of magnitude higher in apartment buildings. This result was not unexpected since large buildings often have complex distribution systems which are not always maintained. In addition, larger buildings are often associated with low and intermittent water use patterns. These conditions contribute to microbial growth and biofilm formation in the building distribution systems. The age of the plumbing system was determined to have a significant effect on the microbial water quality within the building distribution system. Greater microbial water quality deterioration occurred in the building system which was thirty-two years old compared to one which was only four years old. Augostinos et al's. (1995) conclusions regarding the effect of building age, however, are rather weak because they compared only two buildings.

Fryback and Tuhela-Reuning (2005) measured HPC bacteria concentration in drinking water samples collected from eight different drinking water fountains in five different buildings on a university campus. HPC bacteria concentration was correlated with building plumbing age and frequency of use of the drinking fountain. Fountains which were older and were used less had higher HPC bacteria concentration than those which were newer and used more frequently. This research also found that there was a direct correlation between the concentration of free chlorine in the water and the concentration of HPC bacteria.

Chlorine is considered an ideal disinfectant due to the relatively low cost, high availability and high oxidizing powers. However, there are some important health concerns to be considered when using chlorine. It is a highly toxic substance that has potential for accidental release during transport or use and public exposure, it has the ability to react with organic constituents to form disinfection by-products (DBPs) which have carcinogenic and mutagenic properties, as well the long term effects of chloro-organics to the environment and population are unknown (Metcalf & Eddy 2003).

Using sodium hypochlorite (liquid form) and calcium hypochlorite (dry form) can eliminate some of the potential concerns which are associated with the use of chlorine. Safety concerns related to the transport, storage and feed of liquid-gaseous chlorine are eliminated (Metcalf & Eddy 2003). Both compounds are slightly more expensive than liquid chlorine.

There are two main reactions that take place when chlorine is added to water: hydrolysis and ionization (Metcalf & Eddy 2003). Hydrolysis can be explained through the combination of chlorine gas with water (Equation 1) to form hypochlorous acid. Both sodium and calcium hypochlorite can be added as free chlorine and will hydrolyze to hypochlorus acid (Equation 2 and 3).

$$Cl_2 + H_2O \leftrightarrow HOCl + H^+ + Cl^- \qquad (1)$$

$$Ca(OCl)_2 + 2H_2O \rightarrow 2HOCl + Ca(OH)_2 \qquad (2)$$

$$NaOCl + H_2O \rightarrow HOCl + NaOH \qquad (3)$$

Ionization can be defined as the dissociation of hypochlorous acid to form hypochlorite ion (Equation 4).

$$HOCl \leftrightarrow H^+ + OCl^- \qquad (4)$$

The distribution of hypochlorous acid (lower pH) and hypochlorite ion (higher pH) is an important distinction. The distribution is affected by pH and it is important to note because the disinfectant efficiency of HOCl is approximately 40 to 80 times greater than that of OCl^- (Metcalf & Eddy 2003).

Chlorine also reacts with some inorganic and organic material, of those reactions the most important reaction is with ammonia and ammonia nitrogen compounds to form chloramines (Reynolds and Richards 1996). The reactions take place in a stepwise manner to form three chloramines; monochloramine (NH_2Cl), dichloramine ($NHCl_2$) and trichloramine (NCl_3) (Equation 5, 6 and 7).

$$NH_4^+ + HOCl \rightarrow NH_2Cl + H_2O + H^+ \quad (5)$$

$$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O \quad (6)$$

$$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O \quad (7)$$

The relative proportion of the chloramines that are formed is a function of the pH of the water and the hypochlorous acid concentration (Reynolds and Richards 1996). Different types of disinfectants will react differently against the bacteria present in the biofilm. It was hypothesised by Le Chevallier et al. (1990) and Le Chevallier (1991) that chloroamines may be better able than free chlorine to penetrate biofilms and inactivate bacteria attached to the pipe wall in a distribution system. Although LeChevallier's study was mostly directed towards municipal distribution systems the same conclusion likely applies to building distribution systems.

Free chlorine is a much stronger oxidant than monochloramine, however, free chlorine is most often consumed before it has time to react with the bacteria within a biofilm; this is due to its fast reaction rate (Le Chevallier 1991). However, chloroamines have a slow reaction rate which allows them time to penetrate the biofilm to inactivate the bacteria (Chen and Stewart 1996). The chloramines are a mostly a function of the amount of pH and the hypochlorous acid present (Reynolds and Richards 1996). All three of the chloramines are a much less powerful disinfectant against pathogenic organism than free chlorine; however, they contribute to the total combined chlorine residual which remains in the water in the distribution system. Total available chlorine refers to the total amount of free chlorine and chloramines (AWWA 1999).

Corrosion of pipe material can have a significant effect on the growth of biofilms and vice versa. Areas of pipe corrosion are typically identified in the municipal distribution system by the utilities companies. However, it can be difficult to locate corrosion in service lines and building distribution systems, as most systems do not evaluate corrosion on a daily basis (Bartram et al. 2003).

Le Chevallier et al. (1990) conducted a study which indicated that the corrosion of pipes can have a significant impact on the effectiveness of chlorine-based disinfectants for inactivation of bacteria present in a biofilm. Free chlorine tends to be more readily impacted by corrosion compared to monochloramine, however, if generalized corrosion is not controlled they are both equally impaired (Le Chevallier et al. 1990). Inhibitors can be used as means to minimize corrosion throughout a distribution system. Typical inhibitors used are polyphosphates as they are useful in preventing calcium build up and precipitation (McNeil and Edwards 2005). However, consideration must be given as to which inhibitor is used as some inhibitors have been reported to increase the release of particulates and soluble lead (McNeil and Edwards 2005).

Areas of localized pitting corrosion in the pipe material can create protective habitats for bacteria growth and can promote the formation and growth of biofilm. Critchley et al. (2001) examined biofilms and microbial influence cuprosolvency in building distribution systems. It was determined that biofilms were associated with the localized pitting corrosion of the copper plumbing (Critchley et al. 2001). Broo et al. (1999) conducted a study which indicated that after one night of water stagnation microbiological organisms which were present in the water lead to the increase in the corrosion rates and in turn the amount of copper that was present in the water.

The type of pipe material can have a significant effect on microbial growth in the municipal and building distribution systems. Pipe material which is of pure inorganic and/or metal material does not typically promote microbial growth (Schoenen 1986). However, pipe material which is organic in nature may promote the growth of microbes as a result of organic constituents being released (Schoenen 1986). It is important to examine all materials and their potential reaction when they come in contact with potable water (Bartram et al. 2003). Pipe material testing procedures are currently in place to examine how the material may react if used in a water distribution system, however, testing is not universal and no material testing procedures have been accepted as standards (Bartram et al. 2003).

The extent of microbial growth and biofilm formation in a building distribution system will depend on several factors. Complex interactions take place between the chemical and physical parameters in the distribution system which will affect the microbiological quality of potable water (Bartram et al. 2003). Increases in HPC bacteria concentration and deterioration of taste, odour and appearance may all be indicators of microbial water quality deterioration. Consideration must also be give to the age of the building distribution system, complexity of the internal plumbing design, type of building structure and the rate of water use.

2.6.3 Best Practices for Optimal Water Quality in Building Distribution Systems

The USEPA (2005) suggests three steps to enhance water quality protection for all building distribution systems. These three steps were identified primarily as a means to minimize lead exposure in schools in the United States; they are however, applicable to overall water quality in large buildings with intermittent water use.

1. Training – raising public awareness to potential problems associated with water quality deterioration, factors which may affect it and possible health effects (USEPA 2005). In turn this step will aid in the promotion of drinking water quality monitoring programs or initiatives.
2. Testing – initial testing of water quality to determine potential preliminary problems. A monitoring program to examine any changes that may occur over time (USEPA 2005).
3. Telling – keeping the general public informed about potential problems and their associated risks, as well as remedial actions that are taking place to rectify and minimize any potential problems (USEPA 2005).

These steps along with remedial actions will help promote awareness of the general public with respect to the possibility of water quality deterioration within any internal building distribution system.

2.7 Literature Review Summary

The research and literature summarized above will aid in the goal of this study to determine best management practices and procedures to obtain optimal water quality in large intermittent use facilities. Past research has lead into the first phase of the study which includes a survey and assessment of drinking water quality within large intermittent use public buildings.

3.0 EXPERIMENTAL METHODS

3.1 Survey Design

The population of buildings in this study was chosen to be all schools located within the Edmonton public school (EPS) system in Edmonton, Alberta, Canada. The building population within the school system was fixed for the 2005/2006 school year; there were 199 schools. Table 2.1 indicates the number of schools broken down by age group. A complete assessment of the water quality within school buildings would require sampling of every individual school in the EPS system, however due to the limitations of time and resources, this was not possible.

Table 1. Breakdown of school types within Edmonton public school system.

Age Group of School within EPS	Number of Schools within each Category
Elementary	130
Elementary / Junior High	20
Elementary / Junior High / Senior High	7
Junior High	27
Junior High / Senior High	3
Senior High	12
Total Number of Schools within EPS	**199**

After further review of the schools in the EPS system by the study steering committee, the school population was sub-divided based on type and function of the school (i.e. elementary, junior high, high school, other) as well as student utilization rates. The student utilization rate was defined in terms of the number of students enrolled at each school relative to 100% student capacity. Out of the total population 8 schools were eliminated based on the fact that they were either no longer classified as schools but as Educational Service Institutions or EPS did not own the buildings.

The schools were assessed using student utilization rate data obtained from the 2004/2005 school year (Figure 1). The steering committee determined that it was not feasible to investigate schools which had a student utilization rate equivalent to less than 40% enrolment, as these schools were not likely to be representative of the EPS school population. In total there were 19 schools which had student utilization rates lower than 40%. These schools were eliminated from the population. In retrospect, it would have also been beneficial to remove schools which were operated at a capacity greater than 120% since they too were not representative of the population; however, in this study these schools were included as part of the study population.

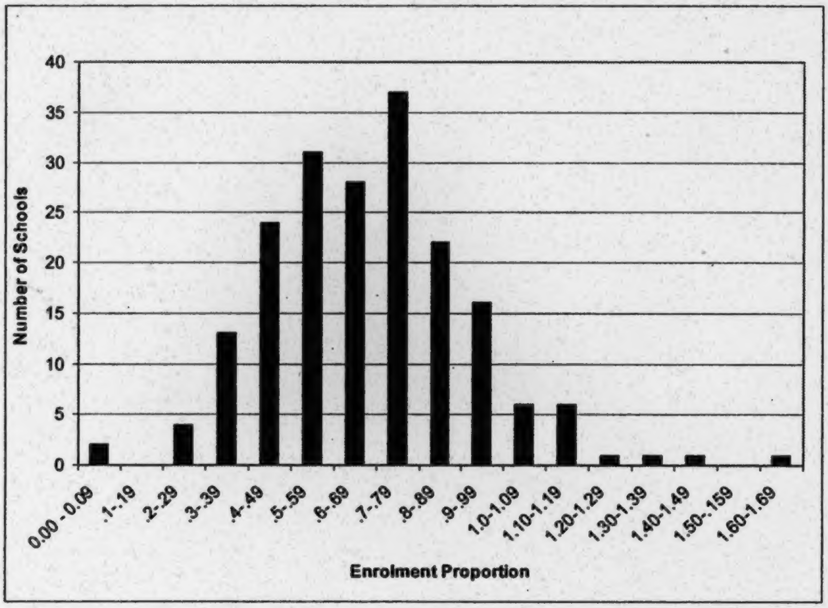


Figure 1. Distribution of student utilization rates of schools in the Edmonton public school system in 2004/2005 proportion.

In total 27 schools were eliminated based on low student utilization rates or re-classification of use. This resulted in the final population of 172 eligible schools, including high schools, junior high schools, and elementary schools.

A semi-random sample of 20 schools was selected from the 172 eligible schools for the water quality study based on two strata – geographical location and building age. A stratified random sample is when a population is divided into distinct sup-populations with individual means and variances. The sample is stratified to take advantage of the distinct sup-populations during analysis. On of the limitations of stratified sampling is that it assumes that the population is uniformly distributed between the geographic strata. For example it was assumed that the age distribution of the school in the different geographic location was identical. Based on the sample size of 20 and the two strata (location and age) schools were randomly selected from each of the nine Edmonton city wards using probability sampling without replacement; 10 schools built prior to 1960 and 10 schools built after 1960 were selected. The cut off date of 1960 was selected as it was the approximate median age of the school population. The nine city wards were grouped into three larger wards based on geographic proximity to each other (Appendix A). The three larger wards were used to represent geographic location and a certain number of schools were chosen from each ward. The incorporation of geographic location as a stratum ensured that the schools selected were representative of the geographic distribution of the total study population. An additional 6 schools were also randomly selected using the same strata. These were designated as "wait-listed" and were to be incorporated into the study should other participants become unable to participate. In this report, the schools will be referred to numerically as schools 1 through 20.

It was assumed that most building users, including staff and students, would use drinking water fountains as their main source of drinking water; therefore sampling was limited to drinking fountains. Other potential drinking water sources, such as kitchen or bathroom sinks or hand-wash stations were not included. With the aid of the principal and custodian, three drinking water fountains at each school were chosen. Each drinking water fountain was classified as a high student and staff use fountain, a medium student and staff use fountain or a low student and staff use fountain.

With input from the principal and the custodian identification of high, medium and low use traffic areas in the building were identified. Based on the identification of these areas fountains were selected. High use fountains were typically located in a busy hallway, beside a gym or beside recess doors. Low use fountains were often located within lower level classrooms (i.e. the kindergarten room). The high and low use fountains were selected first in each building as they were easiest to identify. In the event when there were several fountains to select from, as in the case of selecting the medium fountains, fountain location within the building was considered. Thus, if there were several fountains to select from the fountain was selected which provided the best spatial distribution throughout the school relative to the high and low use fountains which were selected first. Drinking water fountains distributed throughout all areas of the school building would be considered to be the best spatial distribution.

In preparation for the water quality sampling survey, an information e-mail was sent out to all Edmonton Public Schools informing them that the school board had volunteer to participate in the study (Appendix B). This ensured that all principles and their respective schools were informed about the nature of the study and the study objectives. Once the twenty six schools (twenty target and six wait-listed) were selected an information email and consent form was sent out to the respective principals (Appendix C). Confirmation of the participating schools was achieved through a response email to a U of A researchers and EPS staff. In the event that a school did not wish to participate in the study one of the six randomly selected schools which had been wait listed would replace it, depending on the strata that the declining school was in. In general the study was welcomed by most of the school principals and all but four agreed to have their school take part take in the study.

Following confirmation of the twenty schools a visit by a U of A researcher and an EPS representative to the school was scheduled. The purposes of the visit were to:

- provide school principles and staff with a detailed information sheet (Appendix D), a schedule and a note to be included in the school newsletter (Appendix E),
- answer questions that the principle and staff had pertaining to the study, and to
- select the three sampling locations (low, medium and high use) within the building.

3.2 Sampling Protocol

The initial round of water quality sampling was conducted over a period of seven weeks, from October 3, 2005 to November 16, 2005. During this time period, all twenty schools were visited at a frequency of 2 to 4 schools per week. Each of the three sampling locations within each of the twenty schools was sampled twice within the same week; once early Monday morning before the arrival of students or staff, and once late Wednesday morning. Samples collected on early Monday mornings were treated as the worst-case water quality scenario as they represented the first water drawn from the school distribution system since the previous Friday evening. The water in these "first-flush" samples was presumed to have resided in the building plumping piping since the previous Friday evening (approximately 2 ½ days). In order to ensure a "first flush" sample the participating schools were instructed not to use water between the previous Friday evening and the Monday morning when the samples were taken. In some cases there may have been some water use during the restricted times periods. This may have introduced a source of error. This was a practical limitation of the study and it was not possible to monitor or regulate water use at all times. Samples collected on late Wednesday mornings were considered to be representative of normal everyday use.

As a control, water samples were also collected on the same day from a nearby private residence served by the same municipal distribution main as the school being sampled. Residential samples were collected within 1 to 2 hours of the sample being taken at each school. Residential sampling was conducted by an EPCOR Water Services (Edmonton, AB) representative using techniques to ensure the water being sampled was from the municipal water main.

In order to ensure that the water sample collected from the school water drinking water fountains was representative of the water residing within the building distribution system piping, it was essential to collect the sample without flushing the line first. In contrast, taps at the residential houses were left fully open for 5 minutes prior to collecting a sample. This ensured that the service line and household plumbing was thoroughly flushed and that the water sample collected was representative of the water within the municipal water main. All sampling events were conducted in the exact same manner. A detailed description of sampling procedures is outline in Appendix F.

3.3 Water Quality Analysis

The following seven water quality parameters were measured in each water sample collected:

1. Total combined chlorine (EPCOR practices monochloramination)
2. Turbidity

3. Lead
4. Copper
5. Heterotrophic Plate Count (HPC) bacteria
6. Total coliforms
7. *Escherichia coli.*

Table 2 identifies benchmark limits for each parameter. These values were similar to the MACs or AOs set by the Canadian Council of Ministers of the Environment (CCME) in the Canadian Drinking Water Quality Guidelines (HC 2006) and were determined by the steering committee.

With the exception of total combined chlorine residual and lead concentration, all parameters benchmark values were identical to those set by Health Canada. The benchmark level of total combined chlorine residual (i.e. 0.1 mg/L) was selected to provide at least a minimum measurable residual level in the building, but was still less than the 0.5 mg/L minimum which is required in the EPCOR Water Services municipal distribution system (AE 2006). With respect to lead concentration the steering committee selected a benchmark level of 20 ppb rather than the Health Canada guideline of 10 ppb. This was done because the samples were taken from large buildings and it was expected to see somewhat higher concentrations of lead due to the design of the plumbing system, the age of the plumbing system and water flow throughout the plumbing system. This was a decision of the project steering committee. Health Canada has no action with respect to lead concentrations, except that to flush the line for a few minutes before sampling.

Table 2. Benchmark guidelines used in the study derived from Health Canada (2006) guidelines and industry practices[†].

	Guidelines and Industry Practices	
Parameters	**Selected Action Benchmarks**	**Health Canada Guideline 2006 and Industry Practices**
Total Combined Chlorine	> 0.1 mg/L	-
Turbidity	< 5 NTU	≤ 5 NTU[AO]
Lead	< 20 ppb	< 10 ppb[MAC]
Copper	< 1.0 mg/L	≤ 1.0 mg/L[AO]
HPC	< 500 CFU/mL	< 500 CFU/mL[AO]
Coliforms	Absent	Absent[MAC]
Escherichia coli	Absent	Absent[MAC]

[†] Practices conducted at EPCOR Water Services

[AO] Aesthetic Objective

[MAC] Maximum Allowable Concentration

3.4 Analytical Procedures and Quality Assurance and Quality Control

All water quality analyses, with the exception of some field total combined chlorine measurements, were carried out by the EPCOR Water Services Water Quality Assurance Laboratory located at the EPCOR Rossdale water treatment plant in Edmonton, AB. The laboratory is accredited by the Canadian Association for Environmental Analytical Laboratories (CAEAL) to the International Organization for Standardization (ISO) Standard 17025. These standards are based on General Requirements for the Competence of Testing and Calibration Laboratories. Standard methods for the Analysis of Water and Wastewater (APHA, AWWA, WEF 2005) were used for all analytical procedures. The methods used are presented in Table 3.

Table 3. Standard method used for sample analysis.

Parameters	Standard Method Analysis	Standard Method (APHA, AWWA, WEF 1998)
Total Combined Chlorine	Amperometric Titration	4500 – Cl
Turbidity	Nephelometric Turbidity Measurement	2130
Lead and Copper	Atomic Absorption Spectrometry [1]	3500 – Pb 3500 - Cu
HPC	Pour Plate Colony Counting	9215
Coliforms and *Escherichia coli*	Colilert® Presence/Absence	9221

[1] Perkin Elmer AANALYST 600 - AS800 graphite furnace autosampler

The following is a brief outline of the analytical procedures used in order to determine each parameter.

a. *Total Combined Chlorine Residual*

In potable water, total chlorine can be determined amperometrically at pH 4 in the presence of KI (potassium iodide). The total chlorine will include free chlorine and combined chlorine (monochloramine and dichloramine). The amperometric titration method is best when attempting to determine levels of chlorine residual which may be below 0.2 mg/L (APHA, AWWA, WEF 1998). The method detection limit is 0.01 mg/L. In several cases field samples were measured using the DPD (diethyl-p-phenylene diamine) colourimetric method. A portable HACH field kit was used.

b. *Turbidity*

The nephelometric method was employed using a turbidity meter. In this method, the intensity of the scattered light, at 90° to the incident light beam, is measured by a photomultiplier tube (APHA, AWWA, WEF 1998). The turbidity present in the sample is directly proportional to the scattered light intensity produced by the sample (APHA, AWWA, WEF 1998). The method detection limit is 0.02 NTU.

c. *Lead and Copper*

Lead, copper and occasionally zinc, iron and cadmium were analysed using a Perkin Elmer AANALYST 600 atomic absorption spectrometer equipped with an AS800 graphite furnace autosampler. The method detection limit for lead is 0.0002 mg/L (0.2 ppb) and 0.2 mg/L for copper.

d. *Heterotrophic Plate Count*

The general bacteriological quality of the samples was measured using the poor plate method. This is a standard method which attempts to measures the concentration of culturable aerobic heterotrophic bacteria in the water (APHA, AWWA, WEF 1998). Suitable plate counting was obtained by plating 1 mL of the 10^{-2} dilution of the sample. The method detection limit is < 1 CFU/mL

e. *Total Coliforms and Escherichia coli*

The Colilert® Presence/Absence (P/A) test was used for the simultaneous detection and confirmation of total coliforms and *Escherichia coli* in the drinking water samples.

The EPCOR Water Services Water Quality Assurance Laboratory conducted normal QA/QC with respect to all analytical samples analyzed. QA/QC was employed in the field sampling procedures by submitting field blanks and duplicate samples for analysis with regular samples. This was done for approximately 10% of the samples collected.

3.5 Data Evaluation

Data evaluation was conducted using the statistical software SYSTAT 11 (2004). In general most parametric statistical procedures rely on three basic assumptions; normality, randomness and independence (Berthouex and Brown 2002). Based on the experimental design of the study, and the use of a random sample of school buildings, randomness and independence were assumed. Normality of the data was tested using the Shapiro-Wilks (SW) test. According to the SW test, chlorine, turbidity, lead, copper and HPC bacteria concentrations were not normally distributed ($p = 0.000$). A $\log_{10}$ transformation (Berthouex and Brown 2002) improved the approach to normality of the data, but did not result in complete normalization ($p > 0.05$) of the data according to the SW test. Nevertheless, one-way and multiple analysis of variance (ANOVA) were carried out since ANOVA is relatively robust to moderate departures from normality (Berthouex and Brown 2002). Because the normal distribution assumption was violated, even after a logarithmic transformation, factor significance was also assessed using the Kruskal-Wallis (KW) test. The KW test is a nonparametric, distribution free, analog version of the one-way analysis of variance (SYSTAT 11 2004). Coliforms and *Escherichia coli (E. coli)* were excluded from the evaluation as all of the sample results were negative.

All data was presented graphically in the form of box plots. A box plot displays the central tendency, the variation and the distribution of a data set (Six Sigma 2003). The plot provides the 1st quartile, the 2nd quartile (median) and the 3rd quartile. The central box region includes the middle 50 % of the data set, between the first and third quartiles, and is called the inter-quartile range (Berthouex and Brown 2002). The advantage of plotting the median as opposed to the arithmetic average is that the median is less affected by extreme values. The "whiskers" extend to data points that are outside of the inter-quartile range but are not considered outliers (Berthouex and Brown 2002). The Box plot also shows the outlier values. Outliers are defined as points that fall outside a region defined by the median minus 1.5 times the inter-quartile range (lower end) and the median plus 1.5 times the inter-quartile range (upper end). Extreme outliers are values greater than three times the inter-quartile ranges.

4.0 RESULTS AND DISCUSSION

4.1 General Assessment of Building Water Quality

The measured concentration of each parameter was compared to the benchmarks described in Table 2 to assess overall quality of the water within the school buildings. The measured values were also compared to the concentration in the municipal main to assess the change in water quality within the building distribution systems. Distribution system water quality was determined by collecting and analyzing samples from residences that were in close proximity to the schools. The residence building piping was flushed for 5 minutes to ensure that the sample water was representative of the distribution system main in that area and at that time. The water quality results were also compared to the average quality of the finished water produced at the two EPCOR Edmonton water treatment facilities between October to December 2005 and that entered the municipal distribution system. The average distribution system results measured in this study are compared to the average finished water quality for the same time period in Table 4. This comparison suggests there is little deterioration of the water between the time it leaves the water treatment plants until the time it reaches the sample points in the distribution system with respect to the microbiological parameters. A slight decrease is noted in total combined chlorine residual. This may be attributed to travel time and possible reactions with the pipe surface or other organics which may be present in the distribution system. Despite this reduction, on average the total combined chlorine residual remains high throughout the distribution system and is well above the benchmark limit of 0.1 mg/L and the Alberta Environment requirement of 0.5 mg/L. Turbidity, lead and copper tended to increase as the potable water travels through the distribution system. The increase in turbidity may be due to the uptake of sediment particles in the distribution system, as some areas may have a build up of sediment, or to sloughing of biofilm from the surfaces of distribution system piping. The increase in metals (lead and copper) may be attributed to the passage through various unlined and lined pipes throughout the system. It is important to note that the municipal distribution system is not uniform. There are various sizes, types and age of municipal pipes, all which may contribute to parameter concentration changes (Appendix H). Despite the increases within the distribution system, the turbidity, lead and copper levels were still well below the benchmark values of Table 4.

Table 4. Summary of water quality entering the distribution system and residential water main samples.

Parameters	Water Quality Entering the Distribution System[1]	Average Water Main Sample[2]
Total Combined Chlorine	1.97 mg/L	1.74 mg/L
Turbidity	0.053 NTU	0.167 NTU
Lead	0.0002 mg/L	0.001 mg/L
Copper	0.001 mg/L	0.024 mg/L
HPC	1 CFU/mL	1 CFU/mL
Coliforms	Absent	Absent
Escherichia coli	Absent	Absent
Iron	0.003 mg/L	N/A
pH	7.75	N/A
Total Hardness ($CaCO_3$)	181 mg/L	N/A
Calcium Hardness ($CaCO_3$)	126 mg/L	N/A

N/A = not available

[1] Average of daily water quality analysis of finished water produced at EPCORS E. L. Smith and Rossdale water treatment plants between Oct. 2005 and December 2005

[2] Average of samples collected from residences in vicinity of schools during the study period

In the following section, the water quality results from individual schools were pooled and grouped according to sample day (i.e. first-run Monday morning samples or normal use Wednesday samples). The pooled values for each parameter were compared against the benchmarks (Table 2) and distribution system water quality results (Table 4) for each sample day (Monday and Wednesday). Prior to this study, very little information was available on water quality within schools of the Edmonton Public School system. The benchmark comparison provides a snapshot of the overall water quality within the building distribution system sample set and provides baseline information that could potentially be used as a starting point for future studies.

4.1.1 Total Combined Chlorine Residual

EPCOR practices breakpoint chlorination prior to filtration for primary disinfection in both of their Edmonton water treatment plants. They then add ammonia following filtration to react with the residual chlorine to form combined chlorine (primarily monochloramine). An acceptable goal is to achieve 0.2 mg/L of combined chlorine at the farthest tap on the distribution system (Reynolds and Richards 1996). In this study, the available chlorine in the water samples collected from the building and municipal distribution systems was assumed to exist primarily as monochloramine with little or no free chlorine remaining. Only total combined chlorine (which includes monochloramine) was measured. Free chlorine was not measured. The total combined chlorine residual in 55% (33) of the first-run samples collected on Monday morning was below the benchmark limit (0.1mg/L). In comparison, the total combined chlorine residual was below the benchmark in only 10% (6) of the mid-week, normal use samples collected on Wednesday (Figure 2a and 2b). The total combined chlorine residual was below the method detection limit (0.01mg/L) in 13.3% (8) of the samples collected on Monday morning, and in 1.6% (1) of the samples collected on Wednesday. The sampling locations at which the combined chlorine residual was below the benchmark limit on Wednesday were same as those for which the residual was also below the limit on Monday. A total of 120 samples were collected (60 on Monday and 60 on Wednesday) during the study period.

When directly comparing the total combined chlorine residual measured in samples collected in the municipal distribution system to the residual in samples collected from the building distribution systems, there was a clear decrease. Monday morning total combined chlorine building residuals were between 0.973 mg/L and 1.837 mg/L (with one outlier of 0.247 mg/L) lower than the residual measured in the municipal distribution system. For Wednesday late morning building the samples, the decrease was between 0.000 mg/L and 1.367 mg/L.

There was no significant correlation between the total combined chlorine residuals measured in the municipal distribution system and those measured in the building distribution system for both Monday and Wednesday building samples, respectively ($p = 0.245$ and 0.298). This indicates that total combined chlorine depletion is a local issue and occurs somewhere between where the water leaves the municipal distribution system to the head of the drinking water fountain. Further investigation would be needed to characterize the nature of chlorine residual depletion in the building distribution system and to determine if the depletion is occurs uniformly within the distribution system or is more localized.

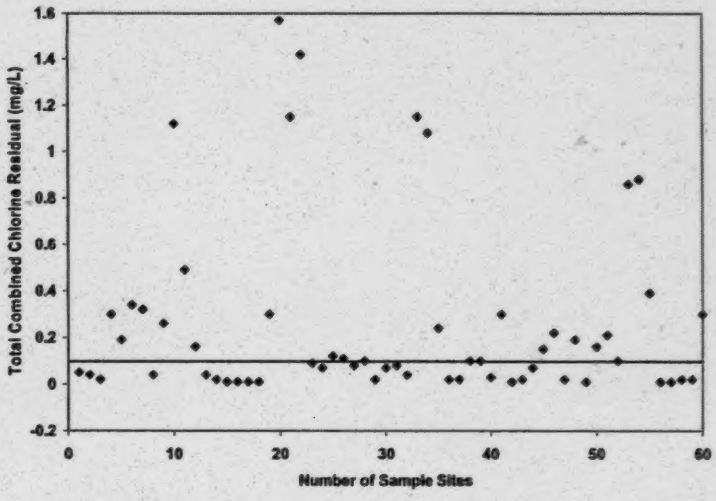


Figure 2a. Total combined chlorine concentration for first-run Monday morning samples collected from all locations. The horizontal line is the benchmark value of 0.1 mg/L total chlorine.

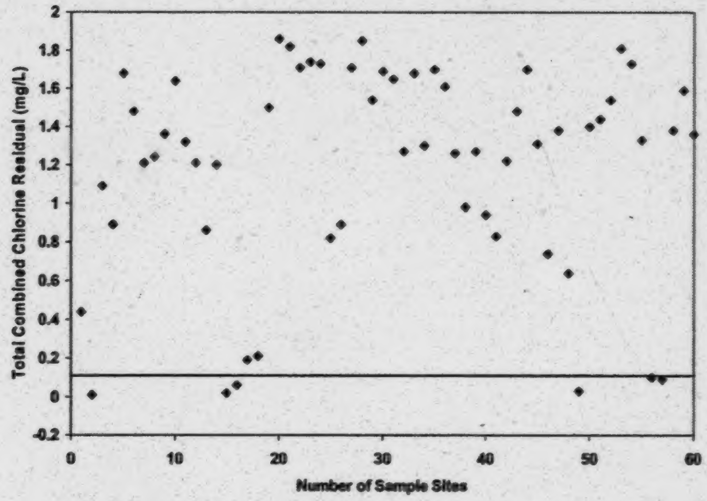


Figure 2b. Total combined chlorine concentration for mid-week, normal use Wednesday samples collected from all sample locations. The horizontal line is the benchmark value of 0.1 mg/L total chlorine.

4.1.2 Turbidity

The measured turbidity was below the benchmark value of 5 NTU in all samples collected (Figure 3a and 3b). In most of the samples the turbidity was less than 1 NTU. The turbidity was greater than 1 NTU in 10% (6) of the samples collected on Monday and in 8% (5) of the samples collected on Wednesday. The highest turbidity measured (3.6 NTU) occurred just after a municipal water mains flushing event occurred in the nearby vicinity and seemed to be an isolate event. The high turbidity events on Monday and mid-week on Wednesday correspond. The sample water fountains which had high turbidity on Monday were the same three which had high turbidity on Wednesday, all of the sample water fountains were located within the same building. These were site specific cases where turbidity was substantially higher in the building distribution system than in the municipal distribution system. The range for the difference between the municipal distribution system and the building distribution system, excluding those two site specific cases was 0.000 NTU to 0.540 NTU on Monday morning and 0.000 NTU to 0.700 NTU on Wednesday.

Table 4 indicates that turbidity concentrations were low upon entering the distribution system (0.053 NTU) and increased, but remained relatively low throughout the municipal mains (0.167 NTU). When examining paired sets of turbidity measurements in building samples and residential samples (taken from the same municipal water main which feeds into the building) there was no relationship between the distribution system turbidity and the building turbidity ($p = 0.714$ and 0.675) for both Monday and Wednesday, respectively.

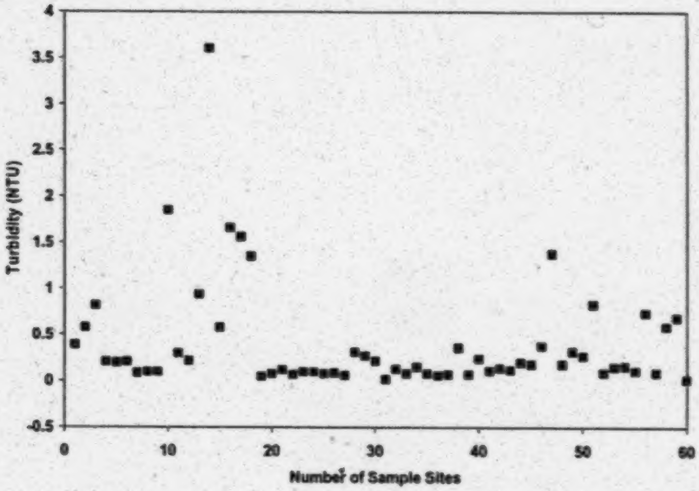


Figure 3a. Turbidity concentration for first-run Monday morning samples collected from all locations. The benchmark value is 5 NTU and is not seen on the Y-axis.

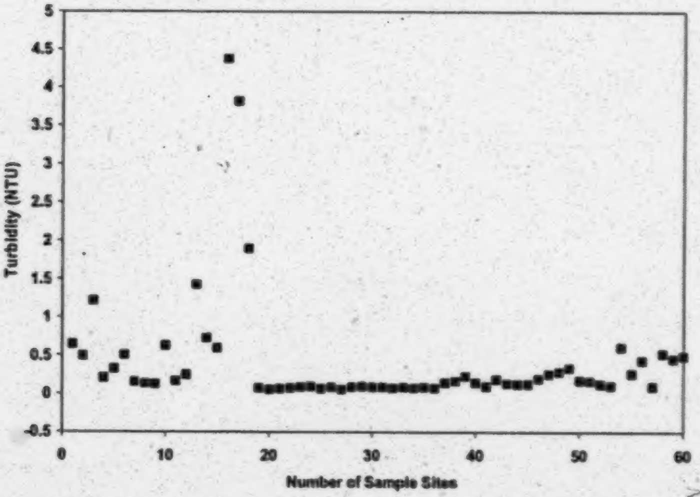


Figure 3b. Turbidity concentration for mid-week, normal use Wednesday samples collected from all sample locations. The benchmark value of 5NTU is at the maximum on the Y-axis.

4.1.3 Lead

The lead concentration was greater than the benchmark limit (20 ppb, Table 2) in 3% (2), and was between 10 and 20 ppb in 10% (6) of the first-run building samples collected on Monday morning (Figure 4a). The lead concentration was below the benchmark in 100% (60) and was between 10 and 20 ppb in 3% (2) of the normal-use Wednesday samples (Figure 4b). In all water fountains but two, the lead concentration in the samples was below the benchmark limit of 20ppb for both Monday and Wednesday samples. That is, the above benchmark lead concentrations were concentrated at two of sixty sampled drinking water fountains. This tends to suggest that elevated lead concentrations are isolated cases possibly related to the local plumbing fixtures.

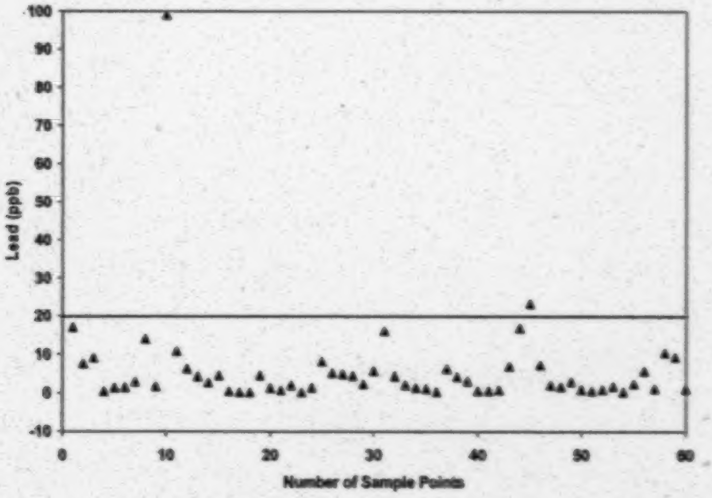


Figure 4a. Lead concentration in first-run Monday morning samples collected from all sample locations. The horizontal line is the benchmark value of 20 ppb lead.

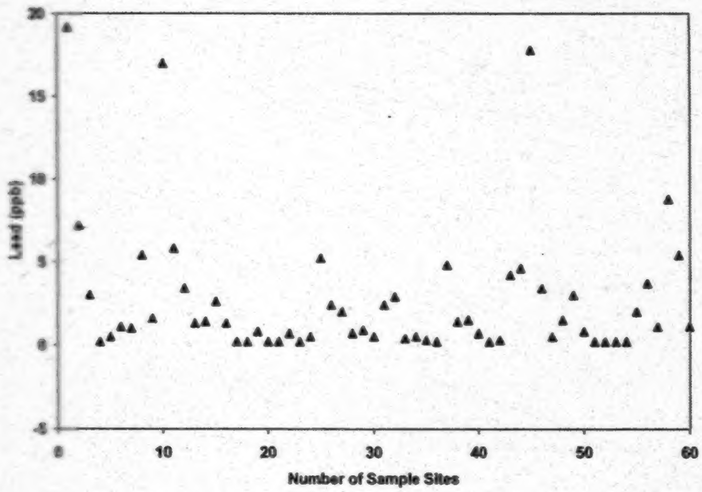


Figure 4b. Lead for mid-week, normal use Wednesday samples collected from all sample locations. The benchmark value of 20 ppb is set at the maximum on the Y-axis.

4.1.4 Copper

The copper concentration in water samples collected from 8% (5) of the water fountains on Monday morning was above the benchmark limit (1.0 mg/L). The copper concentration in water samples collected from 5% (3) on Wednesday was above the benchmark limit (Figure 5a and 5b). Like lead, these cases of elevated copper in the building distribution system appeared to be associated with specific sample locations and buildings.

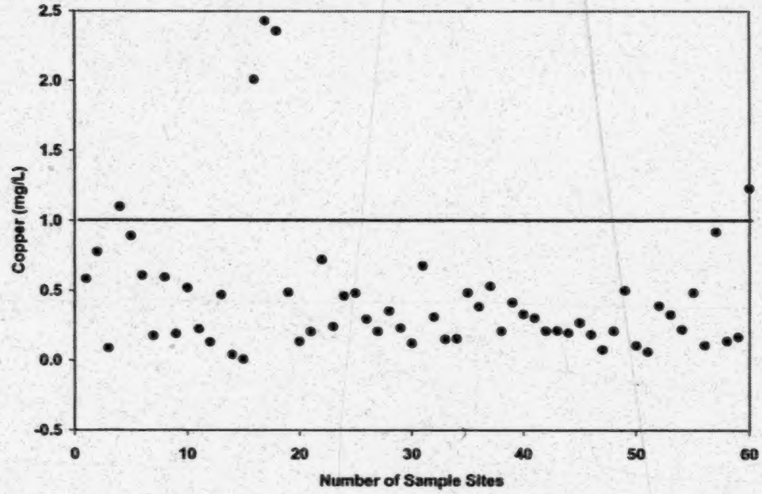


Figure 5a. Copper concentration in first-run Monday morning samples collected from all sample locations. The horizontal line is the benchmark value of 1.0 mg/L copper.

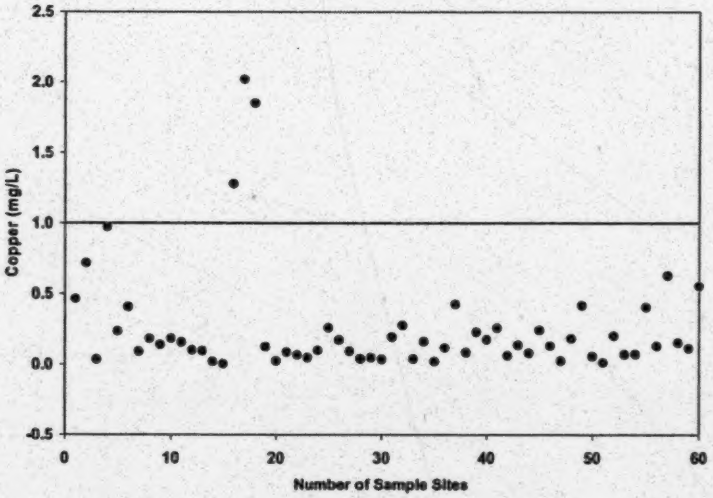


Figure 5b. Copper for mid-week, normal use Wednesday samples collected from all sample locations. The horizontal line is the benchmark value of 1.0 mg/L copper.

4.1.5 Microbiological Data

The HPC bacteria data indicated that 28% (17) of sample water fountains were above the set benchmark limit (500 CFU/mL, Table 2) on Monday, while only 3% (2) were above the limit on Wednesday (Figure 6a and 6b). The base 10 logarithm of the measured HPC concentration is presented in Figures 6a and 6b. The log transformation is appropriate because bacterial concentrations tend to be log-normally distributed (Berthouex and Brown 2002). All school samples were negative for *E. coli* and coliforms during the study.

The results of residential sampling indicate that the HPC bacteria concentration did not increase in the municipal distribution system relative to the finished water produced at the treatment plants (Table 4). The HPC bacteria concentration in the in the municipal distribution system ranged from <1 CFU/mL to 2 CFU/mL on Monday and on from <1 CFU/mL to 3 CFU/mL on Wednesday. In comparison, the HPC bacteria concentration in the building distribution system ranged from 1 CFU/mL to 12,000 CFU/mL on Monday morning and from 1 CFU/mL to 1100 CFU/mL on Wednesday morning. This suggests that, microbiological quality of the water tends to degrade within the building distribution system and/or the associated service line.

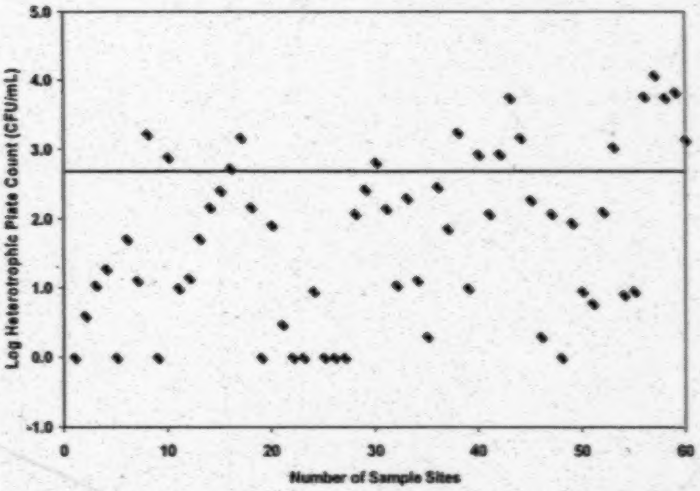


Figure 6a. HPC concentration in first-run Monday morning samples collected from all sample locations. The horizontal line is represents the benchmark value of 500 CFU/m HPC bacteria concentration (=2.7 Log_{10})

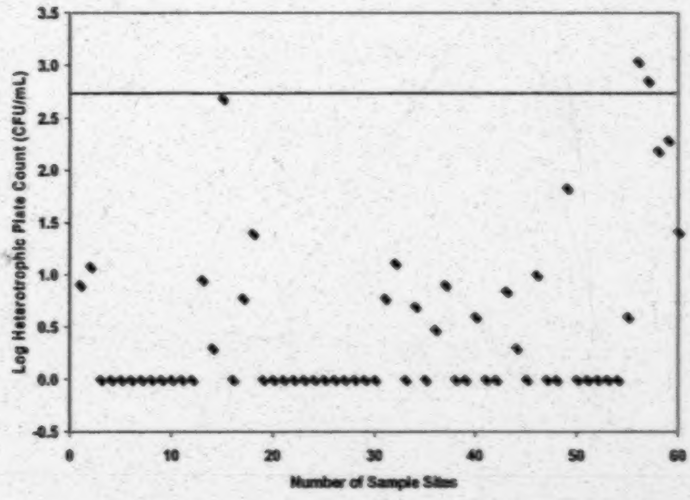


Figure 6b. HPC concentration for mid-week, normal use Wednesday samples collected from all sample locations. The horizontal line is represents the benchmark value of 500 CFU/m HPC bacteria concentration (=2.7 Log_{10}).

4.2 Impact of Experimental Factors on Measured Water Quality

The correlation between four experimental variables and the measured water quality was investigated. The four selected variables are described below:

a. *Sampling Time During the Week*

The results of samples collected on Monday and Wednesday were compared to determine if water quality was a function of time of week that the sample was collect. This was used to determine if there was significant temporal variation in building water quality related to periods of little or no use and water stagnation within the building plumbing.

b. *Sampling Location Within the Building*

The three sample locations within each building were selected based on the approximate level of use of each drinking water fountain. The level of use was a subjective ranking (high, medium or low) and was made with assistance of school staff was based on observed student/staff use at each water fountain.

c. *Water Utilization Rate*

Monthly water utilization (in m^3) were obtained from EPS for each school. Water utilization rates (in m^3/mo) for the months of September through December for 2001-2004 were collected and the average determined to estimate consumption between September and December 2005, the period of the study. Upon completion of the study the 2005 water utilization rates became available and were comparable to the estimated water utilization rates with the 2001-2004 data. The analysis presented is based on the 2001-2004 data.

d. *Building Age*

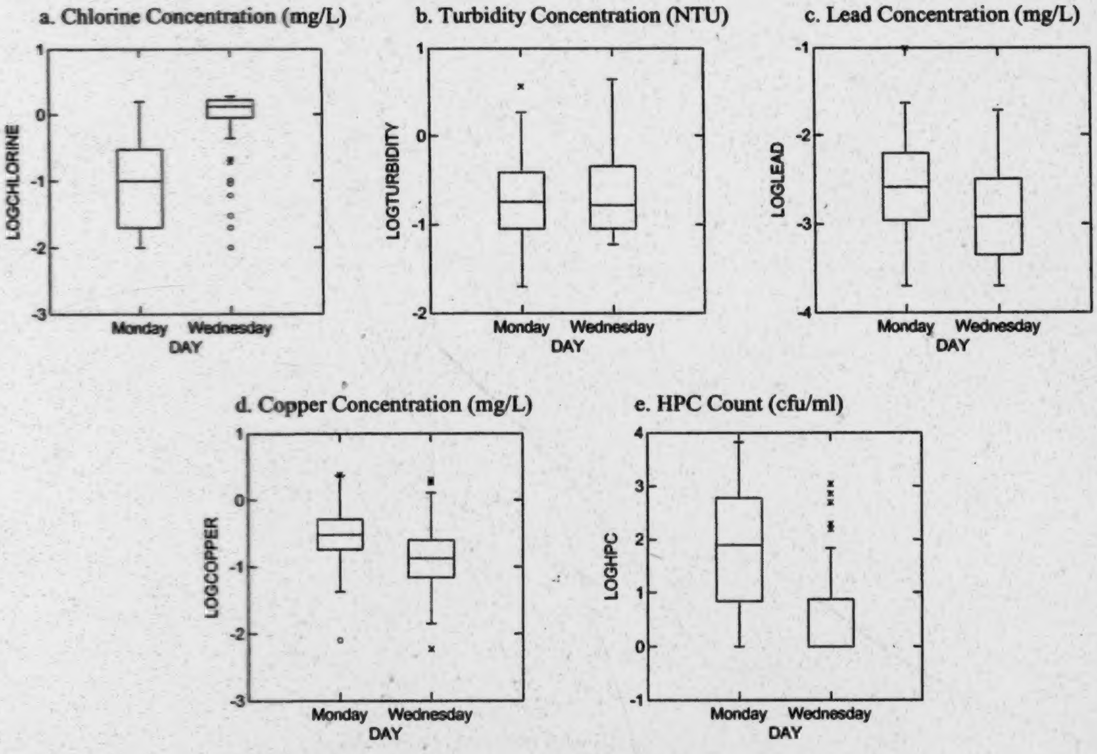
The consideration of building age was important in order to determine if age of the domestic plumbing system had a significant effect on measured water quality parameters. As indicated previously (Section 3.1), the buildings were divided into two groups; those constructed before 1960 versus those constructed after 1960. It was assumed that building age also represented plumbing age, however in some of the study buildings this was not the case due to repairs and renovations. This confounding factor was discovered after the monitoring study began when further investigation was conducted with respect to plumbing age, and represents a potential limitation of the study.

Statistical relationships between these variables and the measured concentrations of each parameter were determined using parametric ANOVA and were confirmed using the non-parametric KW test. In all cases the ANOVA produced the same results as the KW analysis. The p-values are reported as per the KW analysis. The probability value (p-value) is the probability of rejecting the null hypothesis (Berthouex and Brown 2002). Statistical significance is often analysed using a hypothesis test. The null hypothesis (H_0) to be tested was that there was no relationship between the variables and the measured concentration of each parameter. H_0 is presumed to be true until the statistical evidence proves otherwise (Berthouex and Brown 2002). A significance level must be selected at which H_0 will be rejected, the significance level is indicative of the risk associated with falsely rejecting the null hypothesis (Berthouex and Brown 2002). The p-values were compared to the significance level of 5 %, which is equivalent to a 95% confidence level. If the p-value was smaller than the significance level the relationship was considered statistically significant and the null hypothesis was rejected (Six Sigma 2006). With a 5 % significance level the null hypothesis was rejected when the p-value is less than 0.05 ($p < 0.05$). The smaller the *p*-value, the more convincing the evidence that indicates the results were significant (Six Sigma 2006).

4.2.1 Time of Sampling the Week

The results obtained for Monday samples differed significantly from those obtained for Wednesday samples for certain parameters, but not for others (Figure 7). Combined chlorine concentrations (Figure 7a) were significantly lower on Monday compared to Wednesday samples ($p = 0.000$). The combined chlorine results were not unexpected since the water in the building piping was essentially stagnant for 2 to 3 days, thus providing sufficient time for the total combined chlorine to decompose (Brazos et al. 1986). During mid-week Wednesday sampling, the building plumbing was better flushed through normal water use and the total combined chlorine concentration tended to be higher. In some instances the total combined chlorine concentration was less than 0.1mg/L on Wednesday samples. The results suggest that combined chlorine residuals tend to be low following brief periods of low or no use in intermittent-use buildings.

Lead (Figure 7c), copper (Figure 7d) and HPC (Figure 7e) concentrations were significantly greater on Monday compared to Wednesday ($p = 0.002$, 0.000 and 0.000, respectively). Turbidity (Figure 7b) did not vary between sample days ($p = 0.985$). The data also indicates that there were several outliers (*) and extreme outliers (○) within the data set, even after the $\log_{10}$ transformation. For example, several high outliers were detected for HPC bacteria concentration. This suggests that the very high HPC values were not due to normal random variation in HPC concentration but rather, were due to a distinct contamination event at a specific sampling site, assuming that HPC concentration was log-normally distributed. However, due to the robustness of the ANOVA analysis it is possible to include the outlier values.



a. Chlorine Concentration (mg/L)

b. Turbidity Concentration (NTU)

c. Lead Concentration (mg/L)

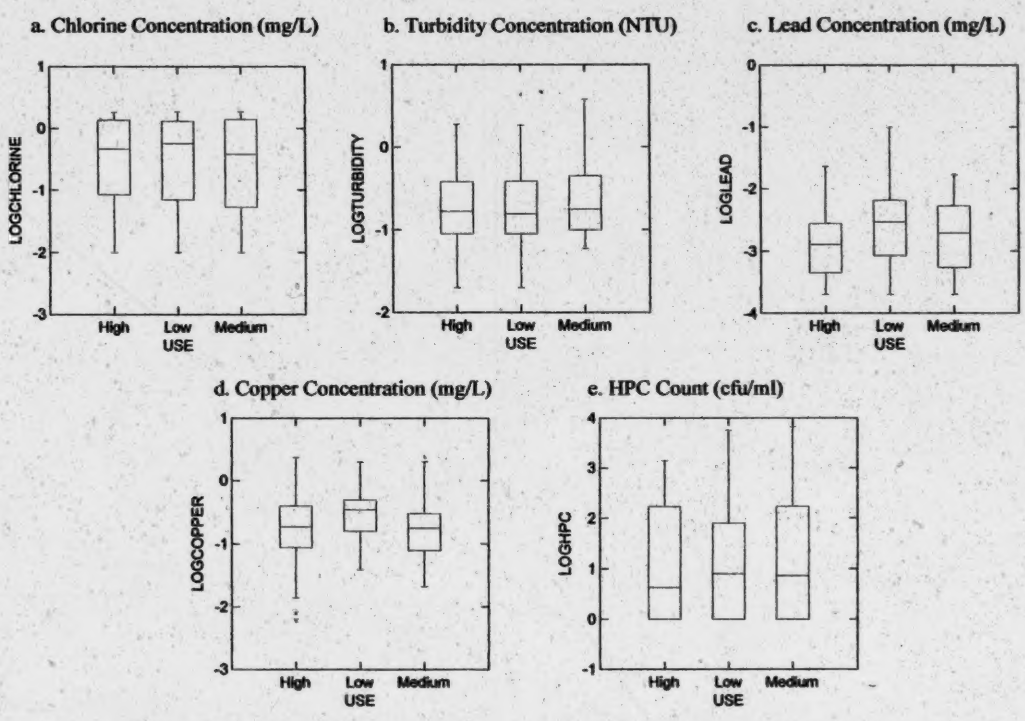
d. Copper Concentration (mg/L)

e. HPC Count (cfu/ml)

Figure 7. Box blots of parameter concentrations for Monday and Wednesday samples collected from all locations.

4.2.2 Sampling Location within the Buildings

The variation in measured water quality parameters between samples collected from those locations that were identified as low, medium and high use water fountains is presented in Figure 8. Total combined chlorine, turbidity and HPC bacteria levels did not vary with sampling site location within the buildings (*p* = 0.975, 0.680 and 0.781, respectively). Lead concentrations did not vary significantly at the 95% confidence level, but did at the 90% confidence level (*p* = 0.059) based on the KW analysis. The ANOVA analysis indicated that lead concentration did depend significantly on location at the 95% confidence level (*p* = 0.037). This suggests that lead concentration may have been dependent on location within the building. Copper levels also varied significantly with within building location ($p = 0.026$). The differences in lead and copper concentrations between locations may have been due to differences in the plumbing materials, the level of water use, or both. Overall, the results suggest that, with possible exception of metals concentration, building location may not be an important factor in determining drinking water quality. For metals such as lead, on the other hand, the concentration may be a function of the material and condition of local plumbing fixtures.



a. Chlorine Concentration (mg/L)

b. Turbidity Concentration (NTU)

c. Lead Concentration (mg/L)

d. Copper Concentration (mg/L)

e. HPC Count (cfu/ml)

Figure 8. Box plots of parameter concentrations as function of within-building sample location.

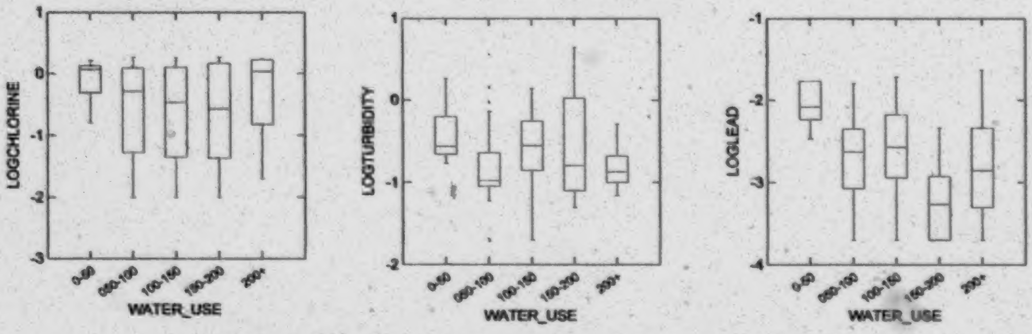
4.2.3 Building Water Utilization Rate

Water utilization rate, expressed as m^3/month, varied widely for each building and was not correlated with building size, or with student utilization rates at the school. The relationships between water quality parameter concentration and water utilization rate (m^3/month) were also highly variable (Figure 9). The individual parameters which have been transformed logarithmically and water utilization rates indicate that the residuals are independent, normally distributed with mean of zero and constant variance. Preliminary analysis was conducted using the ANOVA analysis. There were no statistically significant relationships between water utilization rates and the measured levels of combined chlorine ($p = 0.317$), copper ($p = 0.293$) and HPC bacteria ($p = 0.358$). There were statistical differences in turbidity ($p = 0.021$) and lead (p

= 0.000) at the different water utilization rates. The highest mean turbidity and lead concentration were measured at those facilities with the lowest water utilization rate, typically between 0 to 50 m^3/month.

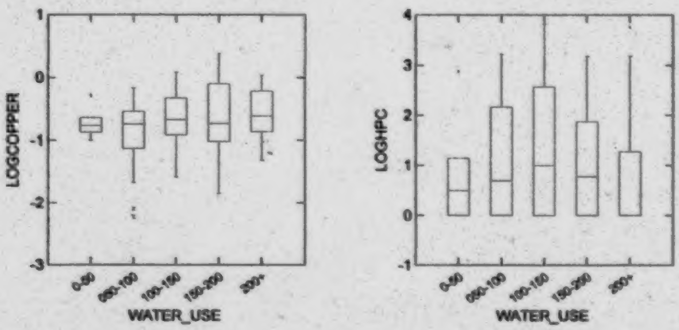
Water utilization within each school is a continuous variable and can therefore be analysed using regression as well. The regression analysis is advantageous because it uses actual water utilization rates for each school rather than categories. Regression increases the amount of information which increases the statistical power. Regression analysis indicated that there were significant relationships between water utilization rates and measured levels of lead (p = 0.000) and copper (p = 0.006). There were no statistically significant relationships between water utilization rates and the measured levels of combined chlorine (p = 0.659), turbidity (p = 0.621), and HPC bacteria (p = 0.362).

The two analyses differ with respect to the significant relationship between water utilization rates and measured levels of turbidity and copper. In retrospect regression analysis should have been implemented as a preliminary statistical tool due to greater statistical power.


a. Chlorine Concentration (mg/L)

b. Turbidity Concentration (NTU)

c. Lead Concentration (mg/L)


d. Copper Concentration (mg/L)

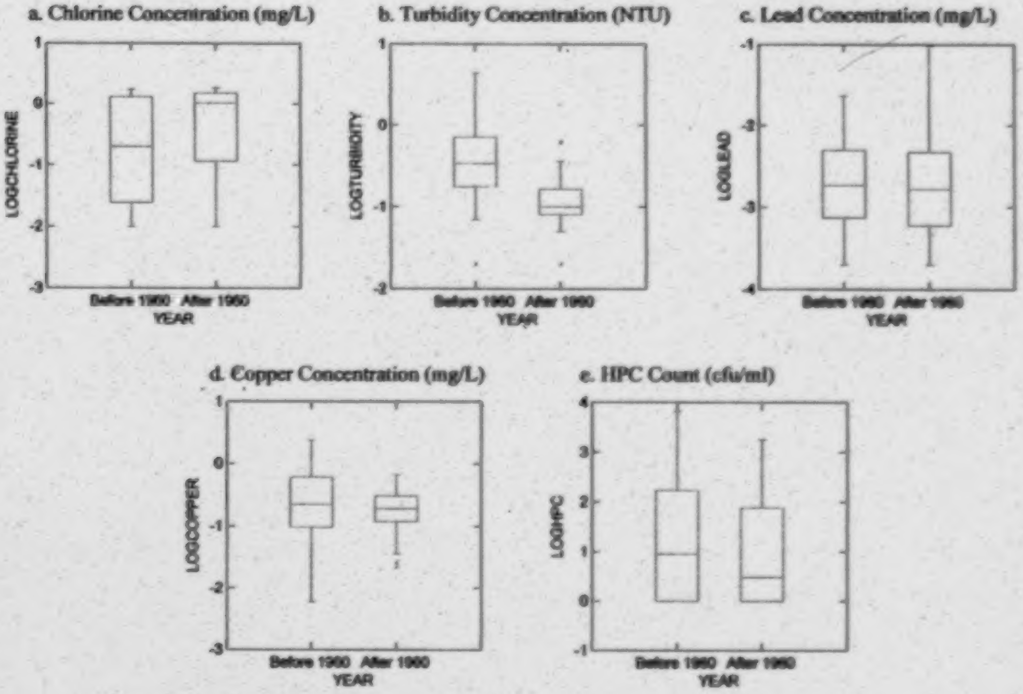
e. HPC Count (cfu/ml)

Figure 9. Box plots of parameter concentrations for water utilization rates (m^3/month)

4.2.4 Building Age

At the outset of the study it was suspected that the measured values of each water quality parameter would be a function of building age. Combined chlorine concentration and turbidity were statistically related to building age (Figure 10). The mean combined chlorine concentration was lower in older (built before 1960) buildings than in newer (built after 1960) buildings (p = 0.0004), while the mean turbidity was higher in older buildings than in newer buildings (p = 0.000). HPC bacteria concentration was marginally related to building age (p = 0.062). Copper and lead were not statistically related to building age (p = 0.168 and 0.535, respectively).

Building age and plumbing age were the same except in one case. In school 6 the copper piping had been replaced and was less than a year old. This happened to be the school which consistently had the highest levels of copper concentration. The data was not adjusted to true plumbing age because this case was extreme and would have skewed the data. Within the first five years that plumbing is installed corrosion can occur in two ways (1) reaction between the pipe material and the water and (2) galvanic corrosion and due to differences in galvanic potential of copper pipe and the solder material (USEPA 2005). This may have been the cause of elevated copper levels in this specific building.


a. Chlorine Concentration (mg/L)

b. Turbidity Concentration (NTU)

c. Lead Concentration (mg/L)

d. Copper Concentration (mg/L)

e. HPC Count (cfu/ml)

Figure 10. Box plots of parameter concentrations as function of building age.

4.3 Additional Discussion of Individual Measured Parameters

4.3.1 Total Combined Chlorine Residual Discussion

The combined chlorine concentration in 31.5% of all samples collected was less than the reference benchmark of 0.1 mg/L (Table 2). EPCOR Water Services produces water at its Edmonton treatment plants with a combined chlorine residual of approximately 2.0 mg/L. All (100%) of the residential samples were well above the 0.1 mg/L benchmark, with a mean concentration of 1.74 mg/L. This is significant because combined chlorine is often used instead of free chlorine as a distribution system disinfectant due to its superior stability. Although combined chlorine is more stable than free chlorine, it will still degrade substantially within building distribution systems especially after periods during which the water is stagnant within the piping. Although the lack of a combined chlorine residual in itself does not represent a health risk, it is a concern because it means that there may be little or no residual disinfectant protection within the building distribution system water to protect against contamination or bacterial re-growth.

To investigate the effect of flushing on combined chlorine concentrations, time-course samples were collected over a period of one hour while the faucet was kept fully open on Monday, Wednesday and Friday at two schools which consistently had low chlorine levels (Figure 11a and 11b).

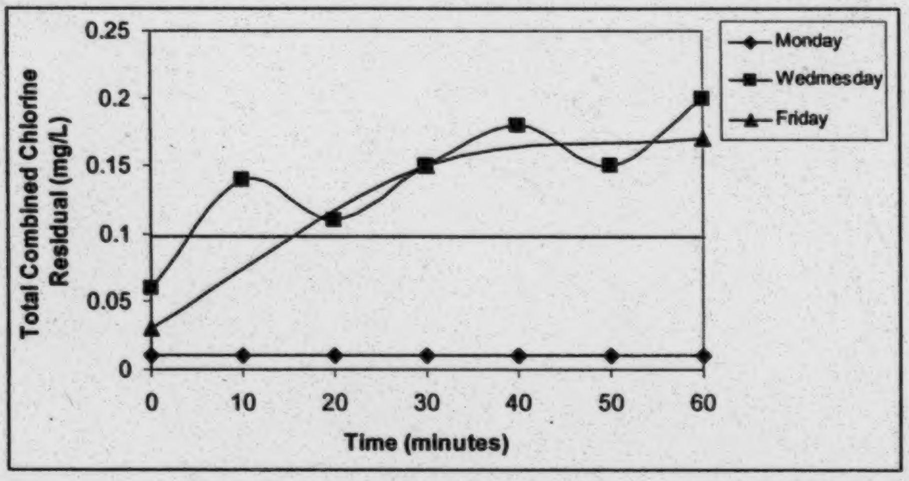


Figure 11a. School 6 total combined chlorine concentration (mg/L) over a one hour time period.

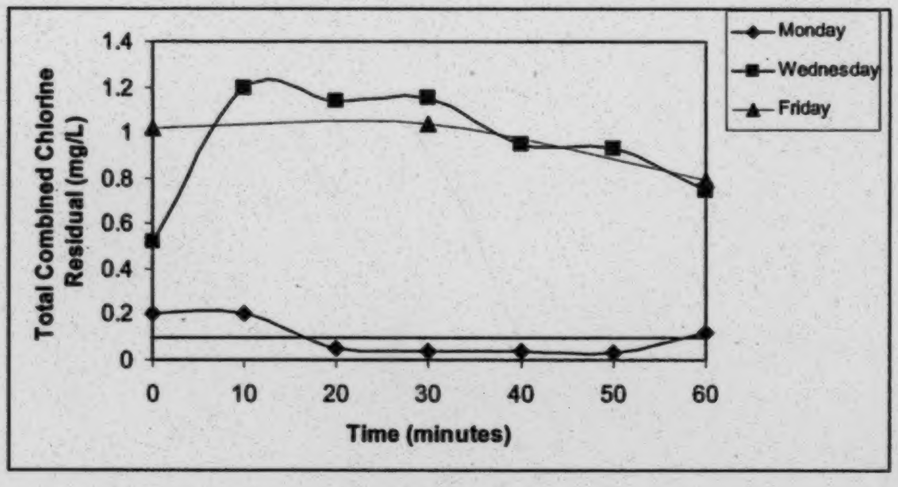


Figure 11b. School 20 total combined chlorine concentration (mg/L) over a one hour time period.

The total combined chlorine residual concentration remained below the benchmark limit of 0.1mg/L on Monday mornings even after an hour of flushing at both schools. In contrast, the combined residual chlorine concentration in School 6 increased with time and exceeded the benchmark value in the tests conducted on Wednesday and Friday. In school 20, however, the chlorine concentration actually began to decrease with time in the Wednesday and Friday tests, although the concentration results remained well above the benchmark limit (Figure 11b)

Overall, these results suggest that although the combined chlorine is relatively stable in the municipal distribution system, the chlorine residual decreases significantly within building piping especially when the water remains stagnant during periods of low, or no, use.

The pipe surface area to volume ratio increases as the pipe size decreases, therefore chlorine depletion would be expected to be greater within building distribution systems than in municipal distribution systems. This assumes that chlorine depletion rate is proportional to pipe surface area. Brazos et al. (1986) conducted a study where they stored flushed water from households and buildings in 50mL glass tubes, as well as in the original plumbing material. They concluded that the chlorine residual could exist for days or weeks in the glass tube, while the chlorine in the water left in contact with the plumbing material was depleted within hours (Brazos et al 1986).

Temperature may also affect chlorine depletion rate. Temperature monitoring was not conducted at all study buildings. However the average water temperature in buildings where water temperature was measured was approximately 24.0°C. Most schools maintain an ambient temperature between 22.0°C to 26.0°C (personal communication with Mike Brown of EPS). The water within the building piping after periods of low or no use (when the water is stagnant) was typically close to ambient building temperature. The accelerated depletion of chlorine at higher temperatures in buildings may also be related to the oxidation reactions with pipe material.

This has been observed in recirculation hot water systems where corrosion and chlorine depletion proceed rapidly (Brazos et al. 1986).

4.3.2 Turbidity Discussion

In general, turbidity results were stable during most of the study. High turbidity was measured in only one of the twenty buildings sampled. This high turbidity event occurred just after municipal water mains flushing event occurred in the nearby vicinity. Nevertheless, the high turbidity of those water samples was still below the benchmark limit of 5 NTU. It should be noted that in March 2006 Health Canada removed the aesthetic limit of 5NTU as a maximum turbidity level. Currently, Alberta Environment is considering setting a distribution system turbidity guideline.

Turbidity was inversely related to water utilization rate (ANOVA analysis) and was directly related to building age (Figures 9b and 10b). Higher water flows will generally result in higher water velocities within building piping. The higher velocities will tend to prevent settling of particulates within the pipes and will result in more thorough flushing of particulate matter from the system. The correlation between turbidity and age may be the result of increased biofilm growth on the older building pipe walls.

4.3.3 Lead and Copper Discussion

Currently copper is related to aesthetic water quality objectives rather than health objectives, although excess levels of copper have been shown to cause gastrointestinal upset (Pizarro et al. 1999). The health effects and concerns associated with lead, on the other hand, are well established (Singh and Mavinic 1991). Overall 1.6% of the samples analyzed had lead concentrations that exceeded the benchmark level of 20 ppb (Table 2). The lead concentration in 3% of the Monday samples was above the benchmark, while the lead concentration in all of the Wednesday samples was below the benchmark. Lead concentration exceeded the 20 ppb benchmark in only two of the twenty buildings sampled. However lead concentrations exceeded the Health Canada Guidelines of 10 ppb in four of twenty buildings at one or more taps.

Although the lead levels exceeded the benchmarks in some instances, the episodes were restricted to first-draw Monday morning samples and the lead concentrations decreased rapidly after flushing of the fixture. Re-sampling was conducted at the sample site which produced the highest levels of lead concentration throughout the study. This re-sampling consisted of a one hour flush of the drinking water fountain, with the valve fully open. During this one-hour period a water samples was collected every ten minutes and the lead concentration measured. The re-sampling was conducted on Monday early morning (Figure 12a) and Wednesday morning (Figure 12b).

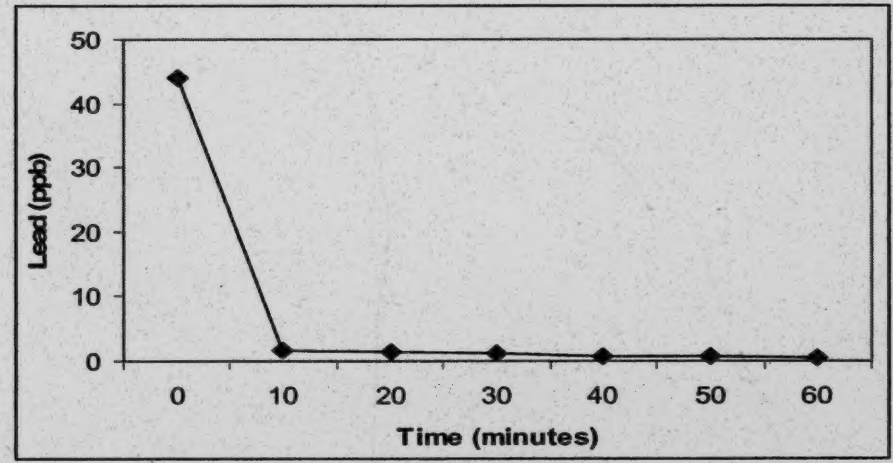


Figure 12a. School 4 Monday morning lead concentration (ppb) over a one-hour time period.

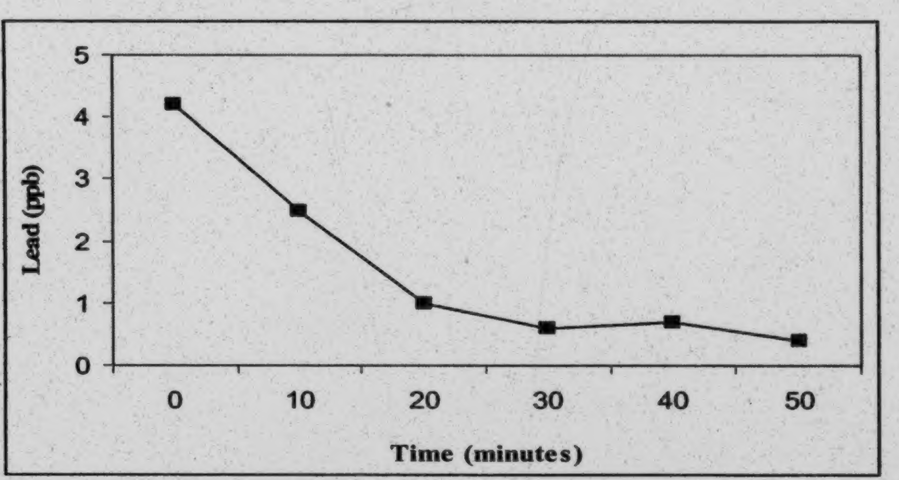


Figure 12b. School 4 Wednesday morning lead concentration (ppb) over a one-hour time period.

Re-sampling indicated that on Monday and Wednesday morning lead concentration began to decrease rapidly within the first five minutes of flushing (Figure 12a and 12b). It would have been beneficial to sample within shorter time increments for the first five minutes of flushing (i.e. every 30 seconds for the first five minutes). This would have better distinguished the flushing time increment where lead concentration drops significantly. It should be noted that the lead concentration in the first sample drawn on Wednesday morning was ten times lower than the first sample drawn on Monday morning. This is probably a result of water use throughout the week and also accounts for the apparent more rapid reduction in the lead concentration during the Monday morning test.

The occurrence of high lead was variable and lead concentrations varied greatly even between sample locations located within the same schools. This suggests that episodes of high lead concentration are likely the result of interactions with fixtures and plumbing materials located very close to the fountains that were sampled. Cantor et al. (2005) found that lead particulates play a significant role in sporadic high lead levels throughout their sampling program. This may have also been a factor in the sample water fountains which produce high levels of lead concentrations. Before atomic absorption analysis is conducted the sample is usually digested at a low pH in order to dissolve any lead particulates. The samples may also be filtered to remove any particulates. The sample digesting and filtering procedures were not carried out during the analysis and in turn lead particulates may have been a factor in some cases of high lead concentrations. In retrospect it would have been beneficial to conduct two lead analyses, comparing the filtered analysis and the non-filtered analysis.

Sampling for lead in an internal drinking water distribution system is a difficult task as lead concentrations will vary unpredictably depending on piping material exposure, type of piping and length of time the water is exposed (Cantor et al. 2005). Typically, the worst case scenario for lead concentration will generally occur after six or more hours of stagnation time within a building distribution system that contains lead piping or lead-brass solder components (Cantor et al. 2005).

Variation of lead concentrations can be observed among different drinking water fountains or other water outlets within the same facility due to differences in flow rates and building plumbing material (USEPA 2005). Further investigation needs to be conducted to determine what factors, such as plumbing design, plumbing solder and fountain models, may be involved.

The maximum acceptable concentration (MAC) for lead in drinking water is 0.010 mg/L (10 ppb), based on CCME Guidelines. The MAC provided by Health Canada is based on a young child with higher than average water intake. It is based on life time water intake and has several built in safety factors. Short-term consumption of water containing lead at concentrations above the MAC does not necessarily pose undue risk to health. The MAC for lead is based on chronic effects and is intended to apply to average concentrations in water consumed for extended periods; short-term consumption of water containing lead at concentrations above the MAC does not necessarily pose undue risk to health (Health Canada 1992). A calculated exposure assessment was conducted using the highest value of lead measured in the experiment for a Monday (i.e. 99 ppb) sample and its subsequent Wednesday sample (i.e. 17 ppb). It was determined that lead exposure from drinking water increased from 10% to 33% (Appendix G).

The local Regional Health Authority (RHA) indicated that there was not enough lead in the small volume of first drawn water to pose a health concern to staff or students. Nevertheless, water fountains where elevated lead levels were observed were examined more closely and as a precaution, suspect drinking water fountains were replaced at two of these locations. The removal of the fountains temporarily prevented any exposure to lead in the water. The decision to shut down drinking water fountains is consistent with the USEPA recommendations for regulating lead levels in schools and day cares (USEPA 2005). Lead and copper levels were measured once the fountains were replaced (Appendix R) and were found to be below the benchmark limit.

The copper concentration exceeded the benchmark level of 1.0 mg/L in 6% of the Monday samples, 10% of the Wednesday samples, and 6% of samples overall. One of the buildings had persistent copper concentrations often in excess of 2.0 mg/L at all three locations for Monday samples and in excess of 1.0 mg/L in mid-week Wednesday samples. In a time-course flushing test, that copper concentration remained high (above the benchmark limit) even after an hour of flushing the tap (Appendix N), however, further flushing of the entire school for twenty minutes reduced levels to well below the benchmark limit (Appendix Q). Flushing of the entire school consisted of running all drinking water fountains and sink faucets for twenty minutes. The high copper and lead levels may have been partially a result of the school plumbing design, which incorporated low-flow water restrictors on taps. It should be noted that the copper plumbing at this school had been renovated and replaced less than one year prior to the water quality survey. Water samples collected from the water main consistently indicated copper and lead levels well below the detection limit. Elevated lead and copper levels in the study buildings, was probably the result of corrosion and leaching in the service lines, as well as the building plumbing and fixtures. The municipal water mains varied widely with respect to size and material. Pipes varied from 50 mm to 450 mm in diameter and consisted of one or a combination of: asbestos cement, cast iron, copper, polyvinyl chloride or steel (Appendix H).

No reliable data was obtained to confirm the material of construction of the service lines connecting the school buildings to the municipal mains. Service line maintenance and records are the responsibility of the building owners and is not the responsibility of the utility company (EPCOR). A survey of the school service lines should be conducted to obtain reliable information on the construction material of the service lines. Depending on the age of the service line, lead may have been used as a material of construction as lead was frequently used in service lines in the past (USEPA 2005). Over time, an oxidation forms a passive layer on lead pipe surfaces, however, vibration can cause flaking off of the 'protective barrier' and increase the chance of lead contamination in the water (USEPA 2005).

Lee et al. (1989) indicated that lead and brass plumbing materials contribute significantly to lead concentrations in first flush water samples and that the contamination is most likely due to valves and solder joints located close to the drinking water faucets. Brass is composed of copper and zinc primarily and is typically machined with lead (USEPA 2005). Older brass fittings are likely to be composed of metal with a higher percent lead concentration than new brass fittings, thus increasing the risk of lead contamination in older buildings (USEPA 2005). The amount of lead that leaches from a fitting made of brass (which contains less that eight percent lead) is dependent on two factors: the corrosiveness of the water and manufacturing process of the fitting (USEPA 2005).

There is greater potential for increased lead and copper concentrations when water is in contact with interior plumbing and fixtures for long periods during low-use periods when water is stagnant within the pipe. This is consistent with the observation in this study that the highest levels of copper and lead were found in samples drawn on Monday mornings (Figure 7).

Age of the study building did not have a significant effect on lead or copper concentrations in drinking water. This result was counterintuitive since buildings constructed prior to 1990 generally contain more lead-based plumbing materials when compared to newer buildings (USEPA 2005). In contrast newer buildings contain more copper piping. All schools in the study had interior copper plumbing (Appendix H).

4.3.4 Microbiological Parameter Discussion

Microbial growth on pipe walls is an important water quality characteristic as it can lead to greater chlorine demand, coliform growth, corrosion of the pipe walls within the distribution system and associated aesthetic problems such as poor taste and odour (Le Puil et al. 2005). When drinking water is stagnant, as in intermittent-use building distribution systems, microbial water quality tends to degrade (Bartram et al. 2003). The HPC concentration exceeded the benchmark level of 500 CFU/mL at least once in 10 of the 20 buildings sampled. In site specific cases where HPC levels were elevated time-course flushing experiments were carried out (Table 5).

Table 5. Effect of fountain flushing on HPC bacteria concentrations.

		Heterotrophic Plate Count CFU/mL				
		Time (minutes)				
Sample Building	**Sample Day**	**0**	**30**	**60**	**90**	**120**
6	**Monday**	2000	2000	1400	*NA*	*NA*
20	**Monday**	43	150	120	*NA*	*NA*
6	**Wednesday**	<1	2	<1	*NA*	*NA*
20	**Wednesday**	120	<1	<1	*NA*	*NA*
19	**Friday**	18	<1	<1	1	<1

Results indicate that HPC bacteria concentration was high on Monday morning and decreased during the week. In most cases, the HPC bacteria concentration began to decrease after only thirty minutes of flushing on Monday mornings. In one case (the Monday sampling event at sample building 20) the number of HPC increased for the first thirty minutes of flushing then began to decrease following another thirty minutes of flushing. Further flushing may have caused water to be drawn into the fountain from areas of the building plumbing with excessive biofilm growth, causing the number of HPC to increase for that period of time. At times later in the week, HPC bacteria concentration decreased more rapidly, within 30 minutes of flushing. In contrast the HPC concentration in the municipal water mains samples never exceeded 1 CFU/ml. It should be noted that the HPC bacterial concentrations alone do not necessarily represent a microbial health risk and are not considered indicators of fecal contamination (Bartram et al. 2003).

When pipe water velocity decreases, sediments can precipitate and create habitats of protection for bacteria to grow (Bartram et al. 2003). Therefore, it can be hypothesised that high turbidity and bacterial concentrations would tend to be correlated. However, ANOVA indicated no statistical relationship between HPC and turbidity in this study (*p* = 0.160).

Temperature is an important factor influencing bacterial growth; growth will be significantly higher when temperatures exceed 15.0°C (Bartram et al. 2003). Although water sample temperature was not measured routinely, it is reasonable to assume that the water temperature within the building plumbing system was close to ambient temperature within the building and ranged between 22.0^{0}C to 26.0^{0}C. Previous studies indicated that fixed pipe biomass were sensitive to temperature increases. Le Puil et al. (2005) found that increasing the temperature from 18^{0}C to 23^{0}C lead to an increase in biomass by the order of one magnitude. However, when temperature was increased to 26^{0}C the biomass increased by five to ten orders of magnitude. The study did not find conclusive evidence with respect to temperature increases and specifically HPCs, however, it was concluded that higher temperatures increased residual chlorine consumption which was correlated to higher levels of HPC (Le Puil et al 2005).

Free chlorine is not as effective of disinfectant as monochloroamine, it has been hypothesized that monochloramine is better able to penetrate biofilms and inactivate attached bacteria (Bartram et al. 2003). The greater the monochloramine residual in the water, the less microbial growth is expected to occur. Brazos et al. (1986) indicated that when measurable residual chlorine concentrations were detected in the distribution system, the HPC values would typically be very low. Often the absence of measurable chlorine residual coincides with elevated bacterial concentrations (Brazos et al. 1986). However, Abu-Shkara et al. (1998) suggests there is evidence that bacteria which are acclimatized to low nutrient drinking water environments have a decreased susceptibility to chlorination. The susceptibility is unknown once organisms slough off into the bulk water phase (Fallowfield et al. 2002).

Although the two were often associated with one another, the results of this study found no correlation between combined chlorine residual and HPC concentration ($p = 0.000$). However, this finding may have been a result of limited statistical power rather than a true lack of relationship. It may be that the sample size was too small in order for the results to indicate a significant relationship between the two variables (HPC and total combined chlorine).

The plumbing material in the buildings studied was copper. Copper is usually more resistant to corrosion than other pipe metals but under the correct conditions, such as elevated water temperature and the presence of biofilms, copper can enter into solution from the copper pipe (Critchley et al. 2001). Organisms in biofilms can produce an extra cellular polymeric substance which can chelate copper and counteract its antimicrobial effects (Fallowfield et al. 2002). Therefore, newer copper pipes may support higher biofilm growth than older copper pipes. Long stagnation periods promote dissipation of chlorine residuals, temperature increase, bacterial growth, and cuprosolvency (Bartram et al. 2003 and Critchley et al. 2001). Correlation analysis indicated a marginal correlation between HPC concentrations and copper concentration ($p = 0.130$) concentrations, which is consistent with cuprosolvency.

Additional samples were collected for odour assessment at those schools with high HPC concentration (above 500 CFU/ml) in order to determine if elevated bacterial concentration was affecting the aesthetic quality of the water (Appendix P). It was thought that high odour intensities would correlate to high levels of HPC, however statistical evidence did not support this ($p = 0.134$).

E. coli and coliform bacteria, in contrast to HPC, are considered direct indicators of fecal contamination of a water supply. All school samples were negative for *E. coli* and coliforms during the study, although one water main sample tested positive for total coliforms. Re-sampling indicated that the positive total coliform result was due to contamination at the sampling point and was not due to water in the municipal distribution system

5.0 CONCLUSION

A baseline water quality survey was conducted in school facilities and the concentrations of selected water quality parameters (combined chlorine residual, turbidity, lead, copper, HPC bacteria) were measured in water samples collected. Samples were also tested for the presence or absence of coliforms and *E. coli*. In certain cases, follow-up sampling was conducted to determine the effect of flushing on certain water quality parameters. Although the primary objective was to address the larger question of water quality in large, intermittent use buildings, the study provided more specific information that Edmonton Public Schools may use to improve the quality of the drinking water within the school buildings. Regarding water quality within the internal school plumbing system, water quality does deteriorate once it leaves the water main and enters the internal plumbing system with respect to certain parameters.

1. The study results indicate that water quality tended to deteriorate within the building distribution systems relative to the water quality in adjacent municipal distribution system. This is consistent with expectations that water quality deterioration will occur in large buildings because of long pipe runs, water sitting at room temperature, dead ends or areas of low flow, and large pipe surface to water ratios (USEPA 2005). The above factors play a role in water quality throughout the building and give rise to the idea that water quality will not be uniform throughout any building.

2. Despite the reduction in water quality relative to the municipal distribution system, the drinking water in the twenty Edmonton Public School buildings sampled during this study is safe for consumption. Although some aspects of water quality were outside of recommended guidelines in several samples, the deviations were not considered sufficient to require notification by Capital Health or public health intervention. At no time

was an immediate concern for the health of staff or students identified. Nevertheless, preventative action to improve water quality was taken in few instances. The findings did suggest that there may be opportunities to improve upon the water quality in Edmonton Public School buildings by implementing regular flushing programs.

3. Total residual combined chlorine concentrations frequently decreased to less than 0.1 mg/L after periods of low, or no, use. It is likely that the chlorine concentrations in the distribution systems of other large intermittent-use facilities will also decrease after periods of low use. The chlorine concentrations increased with normal use of the drinking water fountain but remained less than municipal distribution system levels. These very low chlorine residuals provide little or no protection against bacterial re-growth or contamination in the building plumbing system, however, the levels measured in the study did not present a health risk. Overall, the study results suggest that maintenance of a chlorine residual within all points of the distribution system in large, intermittent use buildings is a significant technical challenge.

4. Total coliform bacteria or *E. coli* were not found in any school water samples. The absence of these bacteriological indicators gives reassurance that there were no health-related concerns in the systems tested. Elevated HPC levels were noted in 10 sample buildings at one or more water fountains. The elevated levels did not pose a health concern. No direct correlation was found between combined chlorine residual and HPC concentrations, but water fountains with chlorine <0.1 mg/L were found to have high HPC. There was no correlation found between elevated HPC levels and odour intensity. The presence of high levels of HPC indicates the potential for bacterial re-growth and the cause of high levels should be investigated.

5. In a small number of samples, lead concentrations exceeded the benchmark values. The lead concentration decreased rapidly with flushing of the fountain which suggests that the concentrations were related to leaching of metal from plumbing material at or near the fountain. As a precaution, two low-use drinking fountains with elevated levels of lead were replaced. The lead content of other fountains in the school district could not be determined without individual testing. However, the data showed that elevated lead levels above the baseline are likely to be sporadic and present only in water from low-use fountains. In general and as indicated by the results low water use will allow more time for lead concentrations to increase in the stagnant water that is in contact with lead-containing metal fixtures.

6. Copper levels were below benchmark values with the exception of one building in which the copper levels were high. This building had recently been renovated with new copper piping. With regular water use and flushing of the building copper levels returned to well below the benchmark level. The elevated levels did not pose a health concern.

7. Four variables were examined to determine if they had significant effects on water quality within the buildings: time of week during which the samples were collected, the level of use of the water fountain, the building water utilization rates and building age. The following conclusions were drawn based on a statistical analysis of the study data:

    a. The time of week when the samples were taken and building age were correlated with the total combined chlorine concentration. Residual chlorine was significantly lower Monday than on Wednesday samples, as well as in buildings built before 1960.

b. Turbidity was significantly higher in buildings which had low water utilization rates (ANOVA analysis) and buildings which were built before 1960.

c. Lead and copper concentrations were significantly higher on Monday samples compared to Wednesday samples. The concentration of the two trace metals (lead and copper) were greatest in fountains which were identified as lowest use within the buildings. The concentrations varied by sampling site locations throughout each building. Lead (ANOVA and regression analysis) and copper (regression analysis) concentrations were significantly greater in buildings which had low water utilization rates; however copper was not affected by water utilization rates. Neither lead nor copper concentration was significantly correlated with building age.

d. The concentration of HPC bacteria was statistically correlated with the time of week at which the samples were taken. HPC concentrations were significantly greater in samples obtained on Monday morning compared to those taken on Wednesday morning. HPC was not statistically related to any other variables or measured parameters (i.e. combined chlorine residual).

8. Measured turbidity was generally less than 1 NTU, and was always less than the Canadian Drinking Water Guideline value for distribution systems (5NTU) throughout the study.

6.0 RECOMMENDATIONS

The main research objective of this study was to assess water quality in large, intermittent use facilities and to determine if the best practices were necessary and should be developed to ensure optimal water quality in these kinds of facilities. The following recommendations were developed from the results of the baseline study and are intended to apply to operation of all large buildings. The recommendations assume that the objective is to achieve water that is stable and of high quality (i.e. that meets or exceeds guidelines for all measurable parameters) and that it is up to the building manager to determine how they wish to achieve the objective:

1. Regular flushing of distribution systems is a good best practice for all buildings regardless of the size and nature of the facility and distribution system. Based on the results of the study, a building flushing program should be undertaken as a good way to improve water quality with respect to the parameters measured in the study. A routine flushing maintenance program will be most effective following periods of low water use. A regular flushing program would improve the water quality, especially with respect to turbidity, HPC, lead and copper concentrations, and will also ensure sufficient chlorine residual and better disinfection protection.

   Further investigation needs to be conducted by Edmonton Public Schools and similar facilities to determine the best method to flush buildings. This may be done on a case-by-case basis. For example, the facility manager may wish to determine the flushing time, volume and frequency required to ensure water quality that approaches that of the municipal distribution system at all points in the building. It may be an unrealistic goal to attempt to achieve a residual chlorine concentration that is equal to that of the municipal distribution system. In this study the criteria of 0.1mg/L was used to indicate the presence of a minimum detectable chlorine residual the building system. A more appropriate goal for public health protection may be to ensure that flushing achieves a chlorine concentration of at least 0.5 mg/L at all points within the building. Once an appropriate flushing method is developed and tested for one building, it may be adapted for buildings of similar size.

2. Normal everyday use and flushing of water fountains will help prevent the build-up of metal concentrations in the water that may tend to occur due to leaching from piping, fixtures or solder material. Since only brief flushing was required to reduce the elevated lead concentrations when they were observed in this study, the most effective way to minimize the potential for human exposure to lead might be to institute a public education program. For example, flushing of the last three feet of the piping before the mouth of the fountain might be sufficient to reduce elevated trace metals concentrations. Users should be instructed to run the water fountain for 60 seconds before taking a drink in order to minimize the potential for exposure to lead especially if the fountain has been unused for an undetermined period of time. If the fountain has been used very recently, then the 60-sec flush may not be necessary.

The study recommendations are consistent with Canadian Drinking Water Guidelines (HC 2006). These guidelines recommend that frequent use of water systems is required to maintaining high water quality. If necessary, water lines within buildings should be flushed periodically. At this point, there are still un-answered questions which require further investigation with respect to implementing a permanent flushing program. Details such as the time and volumes required for flushing, the frequency of flushing, for the optimum day and time of day for flushing, and what and how many fixtures should be flushed need to be determined. A balance must be achieved in order to optimize water quality while still maintaining the integrity of water conservation, as in many case the two often conflict with each other.

While no health risks were identified by the RHA from the study findings, the result of this limited survey of public buildings suggests that further research into water quality in intermittent use buildings is warranted and will help to further improve public health standards for water quality. By examining water quality within buildings instead of the water in the municipal distribution system, the study addressed an under-researched area of water quality management.

Although the study was limited to public school buildings, the results and recommendations of the study likely also apply to a wider range of facilities with low or intermittent water use, such as offices, building complexes and other commercial buildings. In order to assess the water quality in these sites a sampling plan would have to be put in place which established a baseline water quality study and examined the influence of several variables (plumbing age, plumbing material, building type, building age, location and sampling time of week) on measured water quality parameters. It would also be beneficial to examine the effect of flushing with respect to the above variables and water quality parameters. In any case further research would be recommended to assess water quality in intermittent use facilities.

7.0 REFERENCES

Abu-Shkara, F., Neeman, I., Sheinman, R., and Armon, R. 1998. The effect of fatty acid alteration in coliform bacteria on disinfection resistance and/or adaption. Water Science and Technology. **38**(12): pp. 133–139.

Ainsworth, R. 2004. Safe piped water; managing microbial water quality in piped distribution systems. World Health Organization. IWA Publishing, Geneva, SW.

American Water Works Association (AWWA). 1999. Water quality & treatment; a handbook of community water supplies. Fifth Edition. *Edited by* Letterman, R.D. McGraw-Hill, Inc., New York, NY. pp. 14.2-14.48.

APHA, AWWA, WEF. Standard Methods for the Examination of Water and Wastewater - 21th Edition. 2005. Edited by Franson, M.A.H., Clesceri, L.S., Greenberg, A.E., and Eaton A.D. American Public Health Association (APHA), American Water Works Association, and Water Environment Federation, Washington, DC, USA.

Augoustinos, M.T., Venter, S.N., and Kfir, R. 1995. Assessment of water quality problems due to microbial growth in drinking water distribution systems. Environmental Toxicology and Water Quality. **10** (4): pp. 295-299.

Bartram, J., Cotruvo, J., Exner, M., Fricker, C., and Glasmacher, A. 2003. Heterotrophic plate counts and drinking water. World Health Organization. IWA Publishing, Geneva, SW.

Besner, M-C., Gauthier, V., Barbeau, B., Millette, R., Chapleau, R., and Prévost, M. 2001. Understanding distribution system water quality. Journal of the American Water Works Association. **93** (7): pp. 101-114.

Berthouex, P.M., and Brown, L.C. 2002. Statistics for environmental engineers. Second Edition. Lewis Publishers, pp. 13, 16-20.

Brazos, B.J., O'Connor, J.T. and Abcouwer, S. 1986. Kinetics of chlorine depletion and microbial growth in household plumbing systems. American Water Works Association; Water Quality Technology Conference. pp. 239-274.

Canadian Legal Information Institute (CanLIIa). 2006. Potable Water Regulation, Alta. Reg. 277/2003. [online]. Available from http://www.canlii.org/ab/laws/regu/2003r.277/20060310/whole.html [cited 8 May 2006].

Canadian Legal Information Institute (CanLIIb). 2006. Nuisance and General Sanitation Regulation, Alta. Reg. 243/2003. [online]. Available from http://www.canlii.org/ab/laws/regu/2003r.243/20060310/whole.html [cited 8 May 2006].

Cantor, A., De Master, D., and Dukes-Winters, M. 2005. Apples to apples; Recruiting homes for lead monitoring. American Water Works Association; Opflow. **31** (2): pp. 1-6.

Characklis, W.G., and Marshall, K.C. 1990. Biofilms. John Wiley & Sons, New York, NY.

Chen, X., and Stuwart, P.S. 1996. Chlorine penetration into artificial biofilm is limited by a reaction-diffusion interaction. Environmental Science and Technology. **30** (6): pp. 2078-2083.

Critchley, M.M., Cromar, N.J., McClure, N., and Fallowfield, H.J. 2001. Biofilms and microbially influenced cuprosolvency in domestic copper plumbing systems. Journal of Applied Microbiology. **91**: pp. 646-651.

Fallowfield, H.J., Critchley, M.M., Cromar, N.J., and McClure, N. 2002. Biofilms in copper plumbing systems: Sensitivity to copper and chlorine and implications for corrosion. Water Science and Technology. **2**(4): pp. 81-87.

Fryback, J. and L. Tuhela-Reuning. 2005. Slow growing heterotrophic pigmented bacteria as an indicator of water quality in potable water samples. Ohio Journal of Science. **99** (13).

Grigg, N.S. 2005. Assessment and renewal of water distribution systems. Journal of American Water Works Association. **97** (2): pp. 59-68.

Health Canada (HC). 2006. Summary of guideline for Canadian drinking water. Federal–Provincial–Territorial Committee on Drinking Water of the Federal–Provincial–Territorial Committee on Health and the Environment.

Health Canada (HC). 2002. From source to tap; the multi-barrier approach to drinking water. [online]. Available from http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/water-eau/tap-source-robinet/tap-source-robinet_e.pdf [cited 24 February 2006].

Kirmeyer, G.J., Friedman, M., Martel, K.D., Noran, P.F., and Smith, D. 2005. Practical guidelines for maintaining distribution system water quality. In Water quality in the distribution system. Edited by Lauer, W.C. American Water Works Association, United States of America. pp. 5-17.

Lansey, K.E., and Mays, L.W. 1990. Optimization model for water distribution system design. Journal of Hydraulic Engineering. **115** (10): pp. 1401-1418.

Lee, R.G., Becker, W.C., and Collins, D.W. 1989. Lead at the tap: sources and control. Journal of the American Water Works Association. **81**(7): pp. 52-62.

Le Chevallier, M.W., Lowry, C.D., and Lee, R.G. 1990. Disinfecting biofilms in a model distribution system. Journal of American Water Works Association. **85** (7): pp.111-123.

Le Chevallier, M.W. 1991. Biocides and the current status of biofouling control in water systems. Proceedings of the International Workshop on Industrial Biofouling and Biocorrosion. pp. 113-132. Springer-Verlag, NY.

Le Puil, M., Chang, Y.C., Randall, A.A., and Taylor, J.S. 2005. Effects of distribution system material and water quality on heterotrophic plate count and biofilm proliferation. In Water quality in the distribution system. Edited by Lauer, W.C. American Water Works Association, United States of America. pp. 65-78.

McNeil, L.S., and Edwards, M. 2005. Effects of phosphate inhibitors on lead release from pipes. In Water quality in the distribution system. Edited by Lauer, W.C. American Water Works Association, United States of America. pp. 361-385

Pizarro, F., Olivares, M., Gidi, V., and Araya, M. 1999. The gastrointestinal tract and acute effects of copper in drinking water and beverages. Reviews on Environmental Health. **14**(4): pp. 231-238.

Reynolds, T.D., and Richards, P.A. 1996. Unit operations and processes in environmental engineering. Second Edition. PWS Publishing Company, Boston, MA. pp. 114, 740-751.

Schoenen, D. 1986. Microbial alternatives of drinking water by building materials-field observations and laboratory studies. Proceedings of the AWWA Water Quality Technology Conference. pp. 307-317.

Singh, I., and Mavinic, D.S. 1991. Significance of building and plumbing specifics on trace metal concentrations in drinking water. Canadian Journal of Civil Engineering. **18**(6): pp. 893-903.

Six Sigma. 2002. Quality dictionary and glossary – p-value. [online]. Available from http://www.isixsigma.com/dictionary/P_Value-153.htm [cited 10 May 2006].

Six Sigma. 2003. Quality dictionary and glossary - boxplot. [online]. Available from http://www.isixsigma.com/dictionary/Boxplot-196.htm [cited 10 May 2006].

SYSTAT® 11. 2004. Getting started and statistics I, II and III. SYSTAT Software Inc. Richmond, CA.

van Howelingen, G. 2006. The Dutch experience; economics, conservation, pricing. Proceedings of the 12th Canadian National Drinking Water Conference, Saint John, NB, Canada, April 1-4, 2006.

Viraraghavan, T., Subramanian, K.S., and Tanjore, S. 2000. Impact of household plumbing material on trace metal levels in drinking water in Regina, Canada. Proceedings of the ASCE National Conference on Environmental and Pipeline Engineering, Kansas City, MO, United States, July 23-26 2000. pp. 561-570.

United States Environmental Protection Agency (USEPA). 2002a. Potential contamination due to cross-connections and backflow and the associated health risks. [online]. Available at http://www.epa.gov/safewater/tcr/pdf/ccrwhite.pdf [cited 25 March 2006]

United States Environmental Protection Agency (USEPA). 2002b. Effects of water age on distribution system water quality. [online]. Available at http://www.epa.gov/safewater/tcr/pdf/waterage.pdf [cited 20 March 2006]

United States Environmental Protection Agency (USEPA). 2005. Getting the lead out - a guide to reducing lead in drinking water in schools. Office of Water USEPA: 816 – D – 05 – 001.

World Health Organization (WHO). 2004. Guideline for drinking water quality. Third Edition – Volume 1 Recommendations. IWA Publishing, Geneva, SW, pp. 1-21.

APPENDIX A

Map of EPS Ward Breakdown

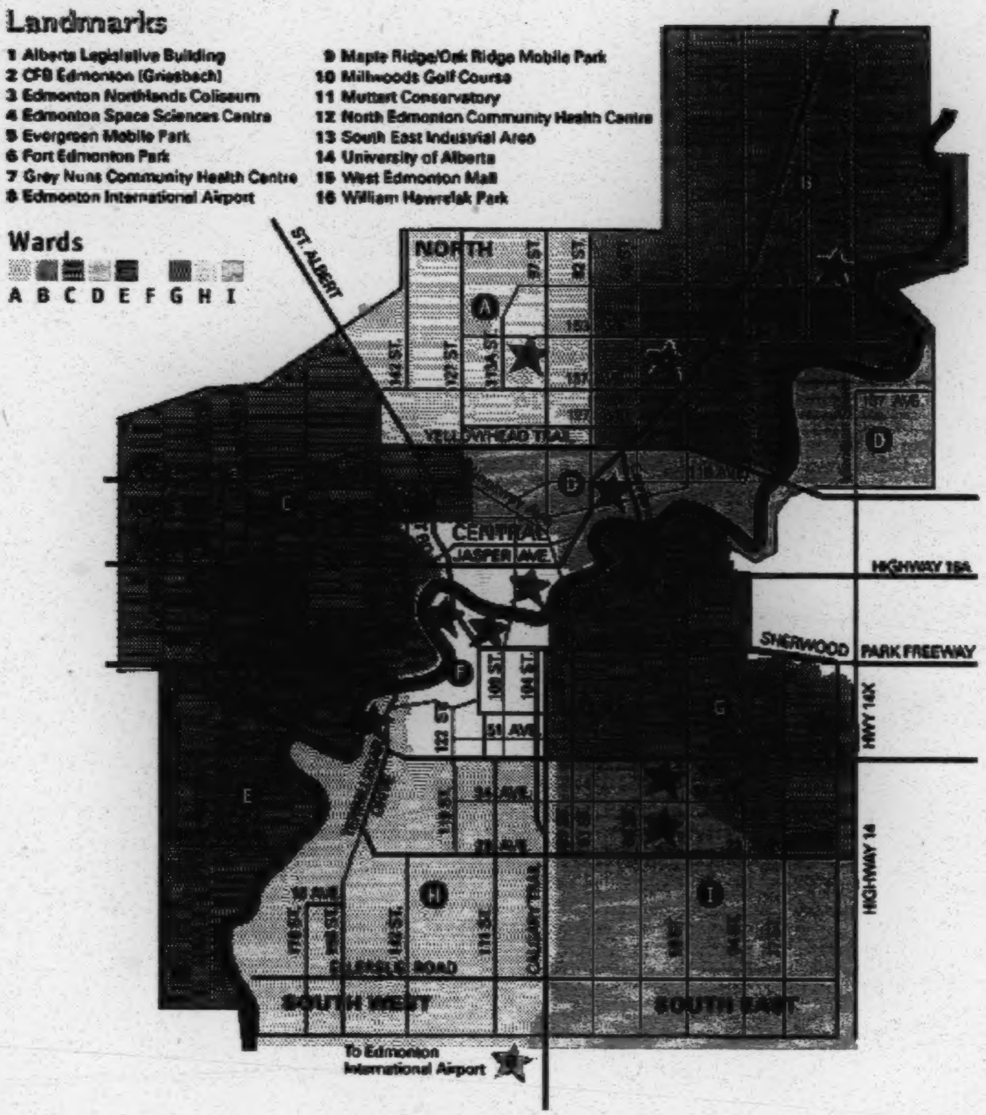

Landmarks
1 Alberta Legislative Building
2 CFB Edmonton (Griesbach)
3 Edmonton Northlands Coliseum
4 Edmonton Space Sciences Centre
5 Evergreen Mobile Park
6 Fort Edmonton Park
7 Grey Nuns Community Health Centre
8 Edmonton International Airport
9 Maple Ridge/Oak Ridge Mobile Park
10 Millwoods Golf Course
11 Muttart Conservatory
12 North Edmonton Community Health Centre
13 South East Industrial Area
14 University of Alberta
15 West Edmonton Mall
16 William Hawrelak Park
Wards
A B C D E F G H I
ST. ALBERT
NORTH
142 ST.
127 ST.
119A ST.
97 ST.
82 ST.
YELLOWHEAD TRAIL
167 AVE.
CENTRAL
JASPER AVE.
HIGHWAY 16A
SHERWOOD PARK FREEWAY
HWY 14X
HIGHWAY 14
122 ST.
109 ST.
104 ST.
51 AVE.
34 AVE.
23 AVE.
119 ST.
CALGARY TRAIL
ELLERSLIE ROAD
SOUTH WEST
SOUTH EAST
To Edmonton International Airport
A
B
C
D
E
F
G
H
I

Figure A1. Division of Edmonton Public School Wards (EPS 2006)

APPENDIX B

Initial Information Sheet

Water quality study

Edmonton Public Schools has volunteered to participate in a water quality study starting in September 2005. The study is a pilot project funded by EPCOR in conjunction with the University of Alberta, Capital Health and the district.

Edmonton Public Schools is confident in the water quality of our schools. We were pleased to volunteer for the study because we want to take every opportunity to ensure the safest environment possible for our staff, students and visitors. Results of the study will be shared with other school districts and large facilities and will help to determine best practices for optimal water quality.

Research will be carried out between September and November 2005 by the University of Alberta and involve 20 district schools. Results of the research will be communicated in 2006.

Edmonton Public Schools is pleased to support this research and welcomes the opportunity to further enhance our high standards for safety.

Further information: Jean Westergard, 429-8373

APPENDIX C

Letter to Principal

Dear Principal,

Edmonton Public Schools has volunteered to participate in a water quality study starting in September 2005. Your school is one of the 26 that was randomly selected from a list of appropriate sites. Only 20 of the 26 school who respond will be able to participate.

Edmonton Public Schools is confident in the water quality of our schools. We were pleased to volunteer for the study because we want to take every opportunity to ensure the safest environment possible for our staff, students and visitors. We encourage you to give your consent to participate and to take this opportunity to further enhance our high standards for safety.

The study is a pilot project funded by EPCOR in conjunction with the University of Alberta, Capital Health and the school district. It is designed to determine best practices for optimal water quality in larger facilities with variable water use patterns.

Data gathering will include two short visits in September and/or October to take water samples and will have a minimal impact on teaching and learning. Immediately important results will be communicated to schools, and the final report will be made public in 2006.

More information about the details and background of the study can be found in the attached information sheet. Please indicate your willingness to participate by filling out the box below and replying to this e-mail by this Friday, September 9.

After receiving your response by e-mail, Kirsten Pinney from the University of Alberta will contact you to schedule sampling visits. Thank you for your co-operation; it is extremely valuable.

School Name:

Contact Person:

School Address:

Postal Code:

Phone No.:

Fax No.:

For more information, contact:

Jean Westergard

Edmonton Public Schools

Occupational Health and Safety Advisor

Phone: 429-8373, Fax: 429-8436, E-mail: jean.westergard@epsb.ca

Kirsten Pinney

The University of Alberta

Graduate Student in Environmental Engineering

Phone: 492-3441, Fax: 492-8198, E-mail: kpinney@ualberta.ca

APPENDIX D

Information Sheet

EPCOR UNIVERSITY OF ALBERTA EDMONTON PUBLIC SCHOOLS

Capital Health

Water Quality Best Practices Research Study

What is the purpose of the project?

The project is designed to find best practices for ensuring optimal water quality in large facilities. Because many large facilities, such as office buildings or schools, are left almost vacant over weekends or during holidays, they have low or intermittent water use. There is an opportunity to find the procedures and materials that best maintain consistently high levels of water quality in buildings with these water use patterns.

What data will be collected?

The field investigator will be collecting three water samples from taps in each of the 20 schools in the study. The water will be analyzed for a range of parameters typically tested in other areas of the distribution system.

When will the study be conducted?

Data collection, the only stage in which your school will participate, will take place in September and October 2005. The study itself began in April 2005 and the full report will be completed by April 2006.

How will the study affect the school?

Researchers will need very limited access to your school, requiring two visits in either September or October, with each visit lasting approximately one hour. All sampling will be conducted outside of classrooms. The study will benefit from the patience and support of school staff but does not require any assistance or personal information from parents or students.

Who is conducting the study?

EPCOR is conducting the study in conjunction with Edmonton Public Schools, Capital Health, and the University of Alberta, Faculty of Environmental Engineering. There will be two field investigators, both graduate students from the University of Alberta. The primary investigator and contact for the study is Kirsten Pinney. Her contact information is listed at the end of this document.

How will this information be used?

It will be used to identify materials and maintenance procedures that provide the best conditions for maintaining high water quality in larger facilities.

How will the information be reported?

The final report is scheduled for completion and publication in April 2006. Immediately important results will be communicated to the school, Edmonton Public Schools, EPCOR and Capital Health.

What are the benefits of this study?

- Proven best practices for maintaining high water quality in schools;
- hard data on materials and ongoing procedures that enhance environmental safety;
- results that can be used by other school districts and large facilities; and
- increased public awareness of high water quality at schools.

For more information, contact:

Jean Westergard
Edmonton Public Schools
Occupational Health and Safety Advisor
E-mail: jean.westergard@epsb.ca

Kirsten Pinney
The University of Alberta
Graduate Student in Environmental Engineering
E-mail: kpinney@ualberta.ca

Elli Culligan
Edmonton Public Schools
Employee Health Services Assistant
E-mail: elli.culligan@epsb.ca

APPENDIX E

Information for Staff and Students

Water Quality Study

Edmonton Public Schools has volunteered to participate in a water quality study starting in September 2005. Our school is one of the 20 selected to participate. We are confident in our water quality and were pleased to volunteer because we want to take every opportunity to ensure the safest environment possible for our staff, students and visitors.

The study is a pilot project funded by EPCOR in conjunction with the University of Alberta, Capital Health and the school district. Research will be carried out between September and November 2005 by the University of Alberta and will involve sampling of water at various locations in the school. Results of the research will be communicated

in 2006 and will be shared with other school districts and large facilities to help to determine best practices for optimal water quality. For more information, please call the school office.

APPENDIX F
Sampling Details

Sampling Days

Monday and Wednesday

1. Pick up cooler, ice packs and map of where sample building is located. Coolers will have already been packed with all the appropriate material and double checked by U of A researcher.

2. Arrive at the school at approximately 6:00am – 7:15am on Monday and 10:00am – 11:00am on Wednesday. Meet the contact person at the specified location to gain entrance to the building.

Please ensure to always bring your security pass whenever entering the school.

3. Enter the school, sample at all three sites, sample the site which is closest to the water meter first, followed by the middle site and the farthest site from the water meter. Sampling orders were pre-determined on initial visit by rough estimation of proximity to the water meter located in each building.

4. Meet U of A researcher at agreed upon location once sampling is completed. All sample were delivered by U of A researcher directly to EPCOR Water Service Laboratory within a hour of collection.

General Sampling Instructions

1. All bottles will be pre labelled, however each sampler must write on each bottle the time (military time) that the sample was taken.

2. The sampling order at each site will be (ie: the first bottle to be filled):

    i. Total combined chlorine and turbidity – 1L nalgene bottle
    ii. Lead and copper – 1L nalgene bottle that has been acid washed
    iii. Bacteria – 200mL plastic bottle with 0.2mL of a 10% sodium thiosulfate.

3. At each sample site put on a new pair of gloves right before sampling is to begin. This will reduce the risk of cross-contamination.

Specific Sampling Instructions

Turbidity and Total Chlorine – 1L nalgene bottle

1. Turn on tap to moderate flow - do not adjust the flow – do not let water run
2. Fill bottle directly to the top with no head space.
3. Cap tightly and place in cooler.
4. Do not turn off the tap or adjust the flow.

Metals – 1L nalgene bottle that has 'Metals' written on it

1. Do not adjust the flow.
2. Fill bottle to the neck leaving a small air space for mixing.
3. Cap tightly and place in cooler.
4. Turn off tap.

Work quickly while taking the turbidity and metals samples to ensure that the water is not running for a period of time and never adjust the flow between turning the tap or fountain on to turning it off after the metals sample has been taken.

Bacteria – 200mL plastic bottle with 0.2mL of a 10% sodium thiosulfate.

Do not open bottles before use and do not rinse them

1. Use a squeeze bottle containing 100 – 150 ppm bleach to disinfect the outer surface of the tap before taking the bacteria sample.
2. Turn on tap to moderate flow – do not adjust the flow.
3. Check the sample bottle to see if the cap is in place. If the cap has fallen off or is very loose, use another bottle with a proper fitting cap.

4. Hold the sample bottle at the base with one hand and carefully remove the bottle cap with the other hand. Keep the cap right side up. Do not touch the cap or the bottle neck with your fingers. Do not set the cap down or put it in your pocket.
5. Fill the sample bottle to the shoulder (approximately ¾ full). The air space is needed for proper mixing of the sample.
6. Replace the cap immediately and place in cooler.
7. Turn off tap.

APPENDIX G

Lead Exposure

Calculated 7 Day Lead Exposure Assessment

Based on the following parameters:

Lead Exposure:	Monday - 99 ppb = 0.099 mg/L
	Wednesday - 17 ppb = 0.017 mg/L
	Tuesday, Thursday and Friday - 17 ppb = 0.017 mg/L
	Saturday and Sunday - 10 ppb = 0.010 mg/L
Child Age:	0.5 - 5 years*
Daily Water Intake:	0.2 - 0.8 L/day = ~0.6L/day (high estimate)*
Average Child Weight:	13.6 kg*

* Health and Welfare Canada 1992

APPENDIX G

Lead Exposure

Calculated 7 Day Lead Exposure Assessment

Day	Daily Water Intake (L)	Lead Concentration (mg/L)	Water Intake (L) * Lead Concentration (mg/L)
Monday	0.6	0.099	0.0594
Tuesday	0.6	0.017	0.0102
Wednesday	0.6	0.017	0.0102
Thursday	0.6	0.017	0.0102
Friday	0.6	0.017	0.0102
Saturday	0.6	0.01	0.006
Sunday	0.6	0.01	0.006
		Sum	**0.112 mg**

(0.112 mg / 7 days) / 13.6 kg

= 0.001176 mg / kg * d

= 1.17 ug / kg * d

The reference dose set by Health Canada is 3.5 ug / kg * d of lead. However this account lead exposure from many different sources, and not just water. The refer on 10 % exposure from water intake and 90% from other sources.

When 10 % of the reference dose (0.35 ug / kg * d) is compared to 1.17 ug / kg * calculated experimental exposure it is approximately 3.3 times larger.

Therefore, based on the highest observed amount of lead concentration found in throughout the experiment lead exposure from water intake will increase from 10

APPENDIX H

Pipe Material

Site	Municipal Area Supply Pipping	Specific Municipal Supply Line and Diameter	Year Built or Replaced	Internal Building Pipe Material
1	Cast Iron	150mm CI	Unknown	Copper
2	Cast Iron	150mm CI	1960	Copper / Galvanished
3	Polyvinyl Chloride / Abestos Cement	150mm PVC OFF 200mm AC	1980	Copper
4	Cast Iron	150mm CI OFF 250mm CI	1959	Copper
5	Cast Iron	150mm CI OFF 150mm CI	1931	Copper / Galvanished
6	Cast Iron	150mm CI OFF 200mm CI	Unknown	Copper
7	Polyvinyl Chloride / Abestos Cement	150mm PVC OFF 300mm AC	1975	Copper
8	Copper / Abestos Cement	50mm CU OFF 250mm PVC	1994	Copper
9	Copper / Abestos Cement	50mm CU OFF 300mm AC	1967	Copper
10	Abestos Cement	150mm AC OFF 300mm AC	1977 / 1971	Copper
11	Polyvinyl Chloride / Abestos Cement	200mm PVC OFF 300mm AC	1980	Copper
12	Polyvinyl Chloride / Abestos Cement	150mm PVC OFF 450mm AC	1990 / 1978	Copper
13	Polyvinyl Chloride / Abestos Cement	150mm PVC OFF 300mm AC	1977	Copper
14	Polyvinyl Chloride / Abestos Cement	150mm PVC OFF 300mm AC	1982 / 1976	Copper / Galvanished
15	Copper / Polyvinyl Chloride	50mm CU OFF 200mm PVC	1986	Copper / Galvanished
16	Copper / Polyvinyl Chloride	50mm CU OFF 200mm PVC	2003	Copper / Galvanished
17	Cast Iron / Polyvinyl Chloride	100mm CI OFF 200mm PVC	1990	Copper
18	Polyvinyl Chloride / Abestos Cement	150mm PVC OFF 250mm AC	1992 / 1997	Copper
19	Copper / Polyvinyl Chloride	250mm PVC	1998	Copper
20	Cast Iron / Steal	100mm CI OFF 168mm ST	1951	Copper / Galvanished

APPENDIX I

Monday Building Samples

Sample Point	Total Cl (mg/L)	Turb. (NTU)	Pb (mg/L)	Cu (mg/L)	E.Coli (PA/100mL)	HPC (CFU/mL)	TC (PA/100mL)
1-A-M	**0.05**	0.39	**0.0170**	0.586	Negative	<1	Negative
1-B-M	**0.04**	0.58	0.0076	0.777	Negative	4	Negative
1-C-M	**0.02**	0.82	0.0091	0.088	Negative	11	Negative
2-A-M	0.3	0.21	0.0004	**1.100**	Negative	19	Negative
2-B-M	0.19	0.2	0.0014	0.892	Negative	1	Negative
2-C-M	0.34	0.21	0.0015	0.611	Negative	52	Negative
3-A-M	0.32	0.09	0.0029	0.178	Negative	13	Negative
3-B-M	**0.04**	0.1	**0.0140**	0.596	Negative	**1700**	Negative
3-C-M	0.26	0.1	0.0017	0.191	Negative	1	Negative
4-A-M	1.120	1.850	**0.0990**	0.5210	Negative	**780**	Negative
4-B-M	0.490	0.300	0.0108	0.2280	Negative	10	Negative
4-C-M	0.160	0.220	0.0063	0.1330	Negative	14	Negative
5-A-M	**0.040**	0.940	0.0043	0.4720	Negative	53	Negative
5-B-M	**0.020**	3.610	0.0028	0.0420	Negative	150	Negative
5-C-M	**<0.01**	0.580	0.0046	0.0080	Negative	260	Negative
6-A-M	**<0.01**	1.660	0.0005	**2.0100**	Negative	**540**	Negative
6-B-M	**<0.01**	1.560	<0.0002	**2.4300**	Negative	**1500**	Negative
6-C-M	**<0.01**	1.350	<0.0002	**2.3600**	Negative	150	Negative
6-CD-M	**<0.01**	1.650	<0.0002	**2.5000**	Negative	150	Negative
6-MSR-M	**<0.01**	**5.700**	**0.0520**	**2.4600**	Negative	**3200**	Negative

APPENDIX I

Monday Building Samples

Sample Point	Total Cl (mg/L)	Turb. (NTU)	Pb (mg/L)	Cu (mg/L)	E.Coli (PA/100mL)	HPC (CFU/mL)	TC (PA/100mL)
7-A-M	0.3	0.05	0.0046	0.489	Negative	<1	Negative
7-B-M	1.57	0.08	0.0013	0.138	Negative	83	Negative
7-C-M	1.15	0.12	0.0007	0.209	Negative	3	Negative
8-A-M	1.42	0.07	0.0020	0.724	Negative	<1	Negative
8-B-M	**0.09**	0.1	<0.0002	0.244	Negative	<1	Negative
8-C-M	**0.07**	0.1	0.0014	0.464	Negative	9	Negative
8-B-M-RS (15min)	1.9	0.08					
9-A-M	0.12	0.08	0.0081	0.485	Negative	<1	Negative
9-B-M	0.11	0.09	0.0052	0.299	Negative	<1	Negative
9-C-M	**0.08**	0.06	0.0049	0.210	Negative	<1	Negative
9-AD-M	**0.09**	0.07	0.0057	0.347	Negative	<1	Negative
10-A-M	0.1	0.31	0.0044	0.357	Negative	120	Negative
10-B-M	**0.02**	0.27	0.0023	0.234	Negative	268	Negative
10-C-M	**0.07**	0.22	0.0057	0.124	Negative	**661**	Negative
10-A-M-RS (15min)	1.77	0.52					
11-A-M	**0.08**	0.02	0.0160	0.680	Negative	142	Negative
11-B-M	**0.04**	0.13	0.0043	0.314	Negative	11	Negative
11-C-M	1.15	0.08	0.0021	0.154	Negative	202	Negative
11-AD-M	**0.05**	0.08	0.0050	0.548	Negative	87	Negative
12-A-M	1.08	0.15	0.0014	0.158	Negative	13	Negative
12-B-M	0.24	0.08	0.0011	0.487	Negative	2	Negative
12-C-M	**0.02**	0.06	0.0003	0.387	Negative	292	Negative

APPENDIX I

Monday Building Samples

Sample Point	Total Cl (mg/L)	Turb. (NTU)	Pb (mg/L)	Cu (mg/L)	E.Coli (PA/100mL)	HPC (CFU/mL)	TC (PA/100mL)
13-A-M	**0.02**	0.07	0.0062	0.534	Negative	73	Negative
13-B-M	**0.1**	0.36	0.0042	0.212	Negative	**1800**	Negative
13-C-M	**0.1**	0.07	0.0031	0.417	Negative	10	Negative
13-CD-M	0.19	0.07	0.0015	0.406	Negative	17	Negative
14-A-M	**0.03**	0.24	0.0006	0.332	Negative	**860**	Negative
14-B-M	0.3	0.11	0.0006	0.305	Negative	120	Negative
14-C-M	**0.01**	0.14	0.0008	0.212	Negative	**870**	Negative
15-A-M	**0.02**	0.12	0.0069	0.214	Negative	**>5700**	Negative
15-B-M	**0.07**	0.2	0.0168	0.199	Negative	**1500**	Negative
15-C-M	0.15	0.18	**0.0232**	0.271	Negative	190	Negative
16-A-M	0.22	0.38	0.0073	0.187	Negative	2	Negative
16-B-M	**0.02**	1.38	0.0021	0.076	Negative	120	Negative
16-C-M	0.19	0.18	0.0017	0.211	Negative	<1	Negative
17-A-M	**<0.01**	0.32	0.0030	0.503	Negative	89	Negative
17-B-M	0.16	0.27	0.0009	0.106	Negative	9	Negative
17-C-M	0.21	0.83	0.0006	0.061	Negative	6	Negative
18-A-M	**0.1**	0.09	0.0009	0.391	Negative	128	Negative
18-B-M	0.86	0.15	0.0018	0.328	Negative	**1100**	Negative
18-C-M	0.88	0.16	0.0003	0.223	Negative	8	Negative

APPENDIX I

Monday Building Samples

Sample Point	Total Cl (mg/L)	Turb. (NTU)	Pb (mg/L)	Cu (mg/L)	E.Coli (PA/100mL)	HPC (CFU/mL)	TC (PA/100mL)
19-A-M	0.39	0.11	0.0024	0.487	Negative	9	Negative
19-B-M	**0.01**	0.74	0.0057	0.109	Negative	**5900**	Negative
19-C-M	**<0.01**	0.09	0.0012	0.922	Negative	**12000**	Negative
20-A-M	**0.02**	0.59	0.0104	0.140	Negative	**5700**	Negative
20-B-M	**0.02**	0.69	0.0093	0.168	Negative	**6800**	Negative
20-C-M	0.3	0.02	0.0011	**1.230**	Negative	**1400**	Negative

APPENDIX J

Wednesday Building Samples

Site	Sample Date	Sample Point	Total Cl (mg/L)	Turb. (NTU)	Pb (mg/L)	Cu (mg/L)	E.Coli (PA/100mL)	HPC (CFU/mL)	TC (PA/100mL)
1	05-Oct-05	1-A-W	0.44	0.65	**0.0192**	0.462	Negative	8	Negative
		1-B-W	**<0.01**	0.5	0.0072	0.718	Negative	12	Negative
		1-C-W	1.09	1.22	0.0030	0.036	Negative	1	Negative
		1-CD-W	1.08	1.23	0.0011	0.014	Negative	<1	Negative
2	05-Oct-05	2-A-W	0.89	0.21	<0.0002	**0.974**	Negative	<1	Negative
		2-B-W	1.68	0.33	0.0005	0.236	Negative	<1	Negative
		2-C-W	1.48	0.51	0.0011	0.406	Negative	<1	Negative
		2-FB-W	<0.01	0.1	<0.0002	<0.001	Negative	120	Negative
3	05-Oct-05	3-A-W	1.21	0.16	0.0010	0.090	Negative	<1	Negative
		3-B-W	1.24	0.14	0.0054	0.182	Negative	<1	Negative
		3-C-W	1.36	0.13	0.0016	0.140	Negative	<1	Negative
4	19-Oct-05	4-A-W	1.64	0.63	0.0170	0.1840	Negative	<1	Negative
		4-B-W	1.32	0.17	0.0058	0.1560	Negative	<1	Negative
		4-C-W	1.21	0.25	0.0034	0.1010	Negative	<1	Negative
		4-FB-W	0.02	0.07	<0.0002	<0.001	Negative	1	Negative
5	19-Oct-05	5-A-W	0.86	1.43	0.0013	0.0940	Negative	9	Negative
		5-B-W	1.20	0.73	0.0014	0.0210	Negative	2	Negative
		5-C-W	**0.02**	0.60	0.0026	0.0060	Negative	488	Negative
6	19-Oct-05	6-A-W	**0.06**	4.38	0.0013	**1.2800**	Negative	<1	Negative
		6-B-W	0.19	3.82	<0.0002	**2.0200**	Negative	6	Negative
		6-C-W	0.21	1.90	0.0002	**1.8500**	Negative	25	Negative
		6-MSR-W	**0.10**	**6.98**	0.0120	**1.7200**	Negative	394	Negative

APPENDIX J

Wednesday Building Samples

Site	Sample Date	Sample Point	Total Cl (mg/L)	Turb. (NTU)	Pb (mg/L)	Cu (mg/L)	E.Coli (PA/100mL)	HPC (CFU/mL)	TC (PA/100mL)
7	26-Oct-05	7-A-W	1.5	0.08	0.0008	0.124	Negative	<1	Negative
		7-B-W	1.86	0.06	<0.0002	0.026	Negative	<1	Negative
		7-C-W	1.82	0.07	<0.0002	0.087	Negative	<1	Negative
		7-FB-W	0.02	0.06	<0.0002	<0.001	Negative	3	Negative
8	26-Oct-05	8-A-W	1.71	0.08	0.0007	0.067	Negative	<1	Negative
		8-B-W	1.74	0.09	<0.0002	0.048	Negative	<1	Negative
		8-C-W	1.73	0.1	0.0005	0.099	Negative	<1	Negative
9	26-Oct-05	9-A-W	0.82	0.07	0.0052	0.258	Negative	<1	Negative
		9-B-W	0.89	0.09	0.0024	0.172	Negative	<1	Negative
		9-C-W	1.71	0.06	0.0020	0.093	Negative	<1	Negative
10	26-Oct-05	10-A-W	1.85	0.09	0.0007	0.039	Negative	1	Negative
		10-B-W	1.54	0.1	0.0009	0.048	Negative	<1	Negative
		10-C-W	1.69	0.09	0.0005	0.036	Negative	<1	Negative
11	02-Nov-05	11-A-W	1.65	0.09	0.0024	0.193	Negative	6	Negative
		11-B-W	1.27	0.08	0.0029	0.276	Negative	13	Negative
		11-C-W	1.68	0.09	0.0004	0.039	Negative	1	Negative
12	02-Nov-05	12-A-W	1.30	0.08	0.0005	0.160	Negative	5	Negative
		12-B-W	1.70	0.09	0.0003	0.022	Negative	<1	Negative
		12-C-W	1.61	0.08	0.0002	0.116	Negative	3	Negative
		12-FB-W	0.02	0.06	<0.0002	<0.001	Negative	19	Negative

APPENDIX J

Wednesday Building Samples

Site	Sample Date	Sample Point	Total Cl (mg/L)	Turb. (NTU)	Pb (mg/L)	Cu (mg/L)	E.Coli (PA/100mL)	HPC (CFU/mL)	TC (PA/100mL)
13	16-Nov-05	13-A-W	1.26	0.15	0.0048	0.425	Negative	8	Negative
		13-B-W	0.98	0.17	0.0014	0.086	Negative	<1	Negative
		13-C-W	1.27	0.23	0.0015	0.227	Negative	<1	Negative
14	09-Nov-05	14-A-W	0.94	0.15	0.0007	0.174	Negative	4	Negative
		14-B-W	0.83	0.1	<0.0002	0.257	Negative	<1	Negative
		14-C-W	1.22	0.19	0.0003	0.061	Negative	<1	Negative
		14-CD-W	1.25	0.5	0.0003	0.044	Negative	<1	Negative
15	09-Nov-05	15-A-W	1.48	0.14	0.0042	0.136	Negative	7	Negative
		15-B-W	1.7	0.13	0.0046	0.081	Negative	2	Negative
		15-C-W	1.31	0.13	0.0178	0.242	Negative	<1	Negative
		15-C-W (15min)			0.0014	0.046			
16	09-Nov-05	16-A-W	0.74	0.2	0.0034	0.131	Negative	10	Negative
		16-B-W	1.38	0.26	0.0005	0.026	Negative	<1	Negative
		16-C-W	0.64	0.29	0.0015	0.182	Negative	<1	Negative
		16-FB-W	<0.01	0.09	<0.0002	0.001	Negative	90	Negative
17	09-Nov-05	17-A-W	0.03	0.34	0.0030	0.416	Negative	68	Negative
		17-B-W	1.4	0.18	0.0008	0.059	Negative	<1	Negative
		17-C-W	1.44	0.17	<0.0002	0.014	Negative	<1	Negative
18	16-Nov-05	18-A-W	1.54	0.13	<0.0002	0.201	Negative	<1	Negative
		18-B-W	1.81	0.11	<0.0002	0.071	Negative	<1	Negative
		18-C-W	1.73	0.61	<0.0002	0.072	Negative	<1	Negative

APPENDIX J

Wednesday Building Samples

Site	Sample Date	Sample Point	Total Cl (mg/L)	Turb. (NTU)	Pb (mg/L)	Cu (mg/L)	E.Coli (PA/100mL)	HPC (CFU/mL)	TC (PA/100mL)
19	16-Nov-05	19-A-W	1.33	0.27	0.0020	0.404	Negative	4	Negative
		19-B-W	**0.1**	0.44	0.0037	0.130	Negative	**1100**	Negative
		19-C-W	**0.09**	0.1	0.0011	0.629	Negative	**720**	Negative
20	16-Nov-05	20-A-W	1.38	0.53	0.0088	0.153	Negative	154	Negative
		20-B-W	1.59	0.46	0.0054	0.113	Negative	195	Negative
		20-C-W	1.36	0.5	0.0011	0.554	Negative	26	Negative
		20-CD-W	1.37	0.47	0.0012	0.548	Negative	30	Negative

APPENDIX K

Monday Municipal Samples

Site	Sample Date	Sample Point	Total Cl (mg/L)	Turb. (NTU)	Pb (mg/L)	Cu (mg/L)	E.Coli (PA/100mL)	HPC (CFU/mL)	TC (PA/100mL)
1	03-Oct-05	Kitchen Tap	1.84	0.15	<0.0002	0.008	Negative	<1	Negative
2	03-Oct-05	Bar Tap	1.82	0.24	<0.0002	0.029	Negative	<1	Negative
3	03-Oct-05	Outside Tap	1.81	0.12	<0.0002	0.018	Negative	<1	Negative
4	17-Oct-05	Kitchen	1.760	0.250	0.0006	0.0270	Negative	1	Negative
5	17-Oct-05	Kitchen	1.580	0.320	0.0170	0.0040	Negative	2	Negative
6	17-Oct-05	Kitchen	1.710	0.330	<0.0002	0.0070	Negative	<1	Negative
7	24-Oct-05	Kitchen	1.98	0.24	<0.0002	0.024	Negative	<1	Negative
8	24-Oct-05	Bathroom	1.89	0.16	<0.0002	0.015	Negative	1	Negative
9	24-Oct-05	Kitchen	1.94	0.13	<0.0002	0.014	Negative	<1	Negative
10	24-Oct-05	Kitchen	1.89	0.07	<0.0002	0.041	Negative	<1	Negative
11	31-Oct-05	Kitchen	1.87	0.07	<0.0002	0.046	Negative	<1	Negative

APPENDIX K

Monday Municipal Samples

Site	Sample Date	Sample Point	Total Cl (mg/L)	Turb. (NTU)	Pb (mg/L)	Cu (mg/L)	E.Coli (PA/100mL)	HPC (CFU/mL)	TC (PA/100mL)
12	31-Oct-05	Kitchen	1.73	0.15	<0.0002	0.028	Negative	<1	Negative
13	14-Nov-05	Bathroom	1.78	0.09	0.0005	0.058	Negative	1	Negative
14	07-Nov-05	Kitchen 0925	0.36	0.08	<0.0002	0.078	Negative	<1	Negative
15	07-Nov-05	Kitchen	1.68	0.24	<0.0002	0.013	Negative	<1	Negative
16	07-Nov-05	Kitchen	1.59	0.21	<0.0002	0.017	Negative	<1	Negative
17	07-Nov-05	Bathroom	1.6	0.13	<0.0002	0.023	Negative	<1	Negative
18	14-Nov-05	Kitchen	1.75	0.1	<0.0002	0.033	Negative	1	Negative
19	14-Nov-05	Kitchen	1.9	0.11	<0.0002	0.019	Negative	<1	Negative
20	14-Nov-05	Kitchen	1.83	0.14	<0.0002	0.033	Negative	<1	Negative

APPENDIX L

Wednesday Municipal Samples

Site	Sample Date	Sample Point	Total Cl (mg/L)	Turb. (NTU)	Pb (mg/L)	Cu (mg/L)	E.Coll (PA/100mL)	HPC (CFU/mL)	TC (PA/100mL)
1	05-Oct-05	Kitchen Tap	1.77	0.09	<0.0002	0.007	Negative	<1	Negative
2	05-Oct-05	Bar Tap	1.49	0.42	0.0004	0.082	Negative	<1	Negative
3	05-Oct-05	Outside Tap	1.67	0.12	<0.0002	0.020	Negative	<1	Negative
4	19-Oct-05	Kitchen	1.530	0.590	0.0170	0.0040	Negative	<1	Negative
5	19-Oct-05	Kitchen	1.780	0.240	0.0004	0.0260	Negative	<1	Negative
6	19-Oct-05	Kitchen	1.520	0.620	<0.0002	0.0060	Negative	<1	Negative
7	26-Oct-05	Kitchen	1.86	0.08	<0.0002	0.018	Negative	<1	Negative
8	26-Oct-05	Bathroom	1.72	0.08	<0.0002	0.012	Negative	<1	Negative
9	26-Oct-05	Kitchen	1.72	0.07	<0.0002	0.012	Negative	<1	Negative
10	26-Oct-05	Kitchen	1.82	0.07	0.0002	0.020	Negative	<1	Negative
11	02-Nov-05	Kitchen	1.87	0.07	<0.0002	0.044	Negative	3	Negative

APPENDIX L

Wednesday Municipal Samples

Site	Sample Date	Sample Point	Total Cl (mg/L)	Turb. (NTU)	Pb (mg/L)	Cu (mg/L)	E.Coli (PA/100mL)	HPC (CFU/mL)	TC (PA/100mL)
12	02-Nov-05	Kitchen	1.76	0.07	<0.0002	0.048	Negative	<1	Negative
13	16-Nov-05	Bathroom	1.75	0.06	<0.0002	0.043	Negative	<1	Negative
14	09-Nov-05	Kitchen	1.64	0.08	<0.0002	0.054	Negative	<1	Negative
15	09-Nov-05	Kitchen	1.75	0.13	<0.0002	0.012	Negative	<1	Negative
16	09-Nov-05	Bathroom	1.71	0.09	<0.0002	0.007	Negative	<1	**Positive**
17	09-Nov-05	Kitchen	1.62	0.1	<0.0002	0.018	Negative	<1	Negative
18	16-Nov-05	Kitchen	1.78	0.1	<0.0002	0.01	Negative	2	Negative
19	16-Nov-05	Kitchen	1.83	0.08	<0.0002	0.031	Negative	2	Negative
20	16-Nov-05	Kitchen	1.83	0.17	<0.0002	0.003	Negative	<1	Negative

APPENDIX M

Building 4 Timed Samples

Site	Sample Date	Sample Point	Time (minutes)	Cd (mg/L)	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)
4	28-Nov-05	4-A-M1	0	<0.0005	0.3400	0.0444	0.1411
	28-Nov-05	4-A-M2	10	<0.0005	0.0290	0.0018	0.0143
	28-Nov-05	4-A-M3	20	<0.0005	0.0200	0.0014	0.0089
	28-Nov-05	4-A-M4	30	0.0012	0.0210	0.0011	0.0097
	28-Nov-05	4-A-M5	40	<0.0005	0.0180	0.0008	0.0062
	28-Nov-05	4-A-M6	50	0.0008	0.0180	0.0008	0.0066
	28-Nov-05	4-A-M7	60	<0.0005	0.0130	0.0006	0.0053

Site	Sample Date	Sample Point	Time (minutes)	Cd (mg/L)	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)
4	30-Nov-05	4-A-W1	0	<0.0005	0.0800	0.0042	0.0446
	30-Nov-05	4-A-W2	10	0.0005	0.0530	0.0025	0.0155
	30-Nov-05	4-A-W3	20	0.0006	0.0200	0.0010	0.0079
	30-Nov-05	4-A-W4	30	<0.0005	0.0135	0.0006	0.0060
	30-Nov-05	4-A-W5	40	<0.0005	0.0149	0.0007	0.0060
	30-Nov-05	4-A-W6	50	0.0010	0.0124	0.0004	0.0052
	30-Nov-05	Leaky bottle and could only collect 6 samples					

APPENDIX N

Building 6 Timed Samples

Site	Sample Date	Sample Point	Time (minutes)	Total Cl (mg/L)	Turb. (NTU)	Cd (mg/L)	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)	HPC (cfu/ml)
6	05-Dec-05	6-A-M1	0	**<0.01**	1.08	<0.0005	**2.0900**	0.0073	0.0188	**2000**
	05-Dec-05	6-A-M2	10	**<0.01**	1.19	<0.0005	**2.1400**	<0.0002	0.0009	NA
	05-Dec-05	6-A-M3	20	**<0.01**	1.23	<0.0005	**2.0200**	<0.0002	0.0118	NA
	05-Dec-05	6-A-M4	30	**<0.01**	1.27	<0.0005	**1.9700**	<0.0002	0.0101	**2000**
	05-Dec-05	6-A-M5	40	**<0.01**	1.34	<0.0005	**1.9100**	<0.0002	0.0063	NA
	05-Dec-05	6-A-M6	50	**<0.01**	1.28	<0.0005	**2.0100**	<0.0002	0.0005	NA
	05-Dec-05	6-A-M7	60	**<0.01**	1.26	<0.0005	**2.0300**	<0.0002	0.0054	**1400**

APPENDIX N

Building 6 Timed Samples

Site	Sample Date	Sample Point	Time (minutes)	Total Cl (mg/L)	Turb. (NTU)	Cd (mg/L)	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)	HPC (cfu/ml)
6	07-Dec-05	6-A-W1	0	0.06	1.25	<0.0005	**1.1200**	0.0002	0.0135	<1
	07-Dec-05	6-A-W2	10	0.14	1.15	<0.0005	**1.1400**	<0.0002	0.0073	NA
	07-Dec-05	6-A-W3	20	0.11	1.11	<0.0005	**1.1600**	<0.0002	0.0056	NA
	07-Dec-05	6-A-W4	30	0.15	1.10	<0.0005	0.9980	<0.0002	0.0051	2
	07-Dec-05	6-A-W5	40	0.18	1.12	<0.0005	0.9630	<0.0002	0.0041	NA
	07-Dec-05	6-A-W6	50	0.15	1.04	<0.0005	**1.0500**	<0.0002	0.0037	NA
	07-Dec-05	6-A-W7	60	0.2	1.06	<0.0005	0.9480	<0.0002	0.0037	<1

APPENDIX N

Building 6 Timed Samples

Site	Sample Date	Sample Point	Time (minutes)	Total Cl (mg/L)
6	09-Dec-05	6-A-F1	0	0.03
	09-Dec-05	6-A-F4	30	0.15
	09-Dec-05	6-A-F7	60	0.17

APPENDIX O

Building 20 Timed Samples

Site	Sample Date	Sample Point	Time (minutes)	Total Cl (mg/L)	HPC (cfu/ml)
20	12-Dec-05	20-A-M1	0	0.20	43
	12-Dec-05	20-A-M2	10	0.10	NA
	12-Dec-05	20-A-M3	20	0.05	NA
	12-Dec-05	20-A-M4	30	0.04	150
	12-Dec-05	20-A-M5	40	0.04	NA
	12-Dec-05	20-A-M6	50	0.03	NA
	12-Dec-05	20-A-M7	60	0.12	120

Site	Sample Date	Sample Point	Time (minutes)	Total Cl (mg/L)	HPC (cfu/ml)
20	14-Dec-05	20-A-W1	0	0.52	120
	14-Dec-05	20-A-W2	10	1.20	NA
	14-Dec-05	20-A-W3	20	1.14	NA
	14-Dec-05	20-A-W4	30	1.15	<1
	14-Dec-05	20-A-W5	40	0.95	NA
	14-Dec-05	20-A-W6	50	0.93	NA
	14-Dec-05	20-A-W7	60	0.75	<1

APPENDIX O

Building 20 Timed Samples

Site	Sample Date	Sample Point	Time (minutes)	Total Cl (mg/L)
20	16-Dec-05	20-A-F1	0	1.02
	16-Dec-05	20-A-F2	30	1.04
	16-Dec-05	20-A-F3	60	0.79

APPENDIX P

Odour Samples

Site	Sample Date	Sample Point	Description	Intensity	HPC
4	12-Dec-05	4-A-M1	Dusty-Earthy-Mouldy-Chlorinous	0.44	Below 500 cfu/ml
	12-Dec-05	4-C-M1	Earthy-Slightly Chlorinous	0.56	Below 500 cfu/ml
6	05-Dec-05	6-A-M1	Oily-Musty-Rubbery-Hydrocarbon	0.75	Above 500 cfu/ml
	05-Dec-05	6-C-M1	Solvent-Oily-Musty-Rubbery-Hydrocarbon	0.88	Above 500 cfu/ml
	23-Jan-06	6-A-MJ	Musty-Dusty-Mouldy-Chlorine	0.75	Above 500 cfu/ml
	23-Jan-06	6-B-MJ	Musty-Dusty-Mouldy	0.58	Above 500 cfu/ml
	23-Jan-06	6-C-MJ	Musty-Dusty-Fishy-Hydrocarbon	0.83	Above 500 cfu/ml
	23-Jan-06	6-WM-MJ	Chlorine-Dusty	0.75	Above 500 cfu/ml
	23-Jan-06	Residential	Dusty-Sweet	0.42	Above 500 cfu/ml
8	23-Jan-06	8-A-MJ	Dusty-Hydrocarbon	0.5	Below 500 cfu/ml
	23-Jan-06	8-C-MJ	Lube-Sweet-Dusty	0.5	Below 500 cfu/ml

APPENDIX P

Odour Samples

Site	Sample Date	Sample Point	Description	Intensity	HPC (>500 cfu/ml)
10	23-Jan-06	10-A-MJ	Chlorine-Dusty	0.5	Below 500 cfu/ml
	23-Jan-06	10-C-MJ	Chlorine-Dusty-Hydrocarbon	0.5	Below 500 cfu/ml
17	23-Jan-06	17-A-MJ	Dusty	0.42	Below 500 cfu/ml
	23-Jan-06	17-C-MJ	Musty-Dusty	0.5	Below 500 cfu/ml
19	23-Jan-06	19-A-MJ	Dusty	0.58	Above 500 cfu/ml
	23-Jan-06	19-C-MJ	Dusty-Hydrocarbon-Rubbery	0.67	Above 500 cfu/ml
20	12-Dec-05	20-A-M1	Dusty-Earthy-Slightly Chlorinous	0.56	Above 500 cfu/ml
	12-Dec-05	20-B-M1	Mouldy-Dusty-Earthy-Slightly Chlorinous	0.56	Above 500 cfu/ml
	23-Jan-06	20-A-MJ	Woody-Dusty-Grassy	0.67	Above 500 cfu/ml
	23-Jan-06	20-B-MJ	Musty	0.33	Above 500 cfu/ml

APPENDIX O

Building 6 Flush Samples

Site	Sample Date	Sample Point	Total Cl (mg/L)	Turb. (NTU)	Cu (mg/L)	Pb (mg/L)	HPC (cfu/ml)	Description	Intensity
6	16-Feb-06	6-A-RF	1.53	0.66	0.1	<0.0002	<1	Musty - Trace Chlorine	0.33
	16-Feb-06	6-B-RF	1.55	0.82	0.068	<0.0002	<1	Rubber - Trace Chlorine	0.33
	16-Feb-06	6-C-RF	1.47	0.68	0.124	<0.0002	<1	Dusty - Plastic - Chlorine	0.5
	16-Feb-06	6-WM-RF	1.67	0.3	0.012	<0.0002	<1	Trace Chlorine	0.33

APPENDIX R

Replaced Fountain Samples

Site	Sample Date	Sample Point	Time (minutes)	Cu (mg/L)	Pb (mg/L)
1	23-Mar-06	1-A-R1	0	0.500	0.0020
	23-Mar-06	1-A-R2	0.5	0.388	0.0057
	23-Mar-06	1-A-R3	1	0.183	0.0044
	23-Mar-06	1-A-R4	3	0.113	0.0037
	23-Mar-06	1-A-R5	5	0.099	0.0046

APPENDIX S

Building 19 Timed Sample

Site	Sample Date	Sample Point	Time (minutes)	Total Cl (mg/L)	HPC (cfu/ml)
19	28-Apr-06	19-B-F1	0	0.02	18
	28-Apr-06	19-B-F2	30	1.23	<1
	28-Apr-06	19-B-F3	60	1.48	<1
	28-Apr-06	19-B-F4	90	1.83	1
	28-Apr-06	19-B-F5	120	NA	<1